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A PROGRAM TO COMPUTE ELF/VLF EARTH-IONOSPHERE MODAL HEIGHT GAINS VIA WKB METHODS UP TO SATELLITE ALTITUDES

RA Pappert
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EM Propagation Division

September 1981

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Released by
JH Richter, Head
EM Propagation Division

Under authority of
JD Hightower, Head
Environmental Sciences Department

METRIC CONVERSION

To convert from	To	Multiply by
gauss	tesla (T)	10^{-4}
degree (angle)	radian (rad)	1.75×10^{-2}

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This report presents a variation of an earlier program for computing ~~ELF/VLF~~ earth-ionosphere waveguide modal height gains. In particular, WKB formalism developed by Budden is used to speed up calculation of height gains in the ionosphere up to satellite altitudes. All quantities needed to calculate mode sums at those altitudes for all field components produced by sub-ionospheric electric dipole sources can be generated with the present program.

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ABSTRACT

This report presents a variation of an earlier program [2] for computing ELF/VLF earth-ionosphere waveguide modal height gains. In particular, WKB formalism developed by Budden [1] is used to speed up calculation of height gains in the ionosphere up to satellite altitudes. All quantities needed to calculate mode sums at those altitudes for all field components produced by sub-ionospheric electric dipole sources can be generated with the present program.

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I. INTRODUCTION

This report represents the implementation of WKB methods [1] for extending ELF/VLF modal height gains in the ionosphere up to satellite heights. In past works [2,3] this extension has been acccomplished by carrying out full-wave integrations up to the satellite altitude. For altitudes sufficiently high in the ionosphere (ie, $\gtrsim$ 110 km for VLF, $\gtrsim$ 150 km for ELF under daytime ionospheres and $\geq$ 250 km for ELF under nighttime ionospheres) the electromagnetic field is in the outgoing whistler mode and the ionospheric gradients are sufficiently weak to justify use of the WKB method. It has been our experience that in carrying fields up to altitudes $\geq$ 500 km, the WKB method will reduce the computer cost (Univac 1100) by about a factor of 1/3 in the lower ELF band ($\approx$ 75 Hz) and by more than an order of magnitude in the VLF band. Thus, with this cost improvement, it seems quite possible that case studies of satellite reception of VLF signals using waveguide concepts such as reported in reference 4 could be extended to global coverage studies.

Implementation of the WKB theory involves no more than modifications of a full-wave fields program [2] developed originally for the purpose of calculating mode conversion coefficients associated with horizontal inhomogeneities in the earth ionosphere waveguide [5]. One departure of the present fields program from that discussed in reference [2] relates to the replacement of the Inoue-Horowitz [6] integration algorithm by the Runge-Kutta algorithm. This change along with the capability to iterate the mode equation and calculate excitation factors was implemented by CH Shellman, of the NOSC EM Propagation Technology Division, in unpublished work. The Runge-Kutta numerical integration of the field equations together with the Gram-Schmidt orthogonalization procedure and normalization of solutions is a procedure first described by Pitteway [7]. The remaining modifications are related specifically to the field matching required to implement the formulas given in [1]. The essence of the method is to calculate via full-wave Runge-Kutta integration the fields up to an altitude called TOPHT. At TOPHT the outgoing whistler mode (or the outgoing wave with minimum attenuation) is extracted from the set of four magneto-ionic modes and then matched to the corresponding full-wave field components. The WKB fields are then propagated to higher altitude using a Simpson rule integration routine which adjusts the step size in order to maintain precision.

Budden's WKB formulas [1] are summarized in section II. Excitation factors, useful if mode sums are ultimately the goal, and WKB mode summing formulas are summarized in section III. Flow of the program and subroutine descriptions are given in section IV. Section V contains a discussion of card deck arrangement for input along with discussion of a sample output. In section VI WKB height gain results are compared with full-wave Runge-Kutta results, and the appendix contains a program listing.

II. SUMMARY OF WKB FORMULAS

For plane wave incidence of an rf wave on the ionosphere, Maxwell's equations can be written as [8]

$$e' = -iTe \tag{1}$$

where the prime denotes $(k^{-1}\partial/\partial z)$, with k the free space wave number, T a 4 x 4 matrix given by Budden [1], and e a column matrix composed of components of the electric ($\vec{E}$) and magnetic ($\vec{H}$) fields of the rf wave. The transpose of e is

$$e^T = (E_x, - E_y, Z_0\mathcal{H}_x, Z_0\mathcal{H}_y) \tag{2}$$

where Z_0 is the free space impedance. Henceforth the notation $H_x = Z_0\mathcal{H}_x$, $H_y = Z_0\mathcal{H}_y$ and $H_z = Z_0\mathcal{H}_z$ will be used.

The matrix T has four characteristic roots or eigenvalues, q_i (i = 1,2,3,4), which satisfy the characteristic equation

$$\det (T - qI) = 0 \tag{3}$$

where I is the unit 4 x 4 matrix. This equation is the Booker quartic. Corresponding to any root q_i there is an eigencolumn $P = s^{(i)}$ which satisfies

$$T\, s^{(i)} = q_i s^{(i)} \tag{4}$$

Let S be the 4 x 4 matrix whose columns are $s^{(i)}$. For points where S is non-singular, the column matrix f can be defined as

$$e = Sf \text{ or } f = S^{-1}e \tag{5}$$

and it can be shown [8] that the elements of f satisfy

$$f'_k = -iq_k f_k + \sum_j \Gamma_{kj} f_j \qquad ; j,k = 1,4 \tag{6}$$

where

$$\Gamma = -S^{-1}S' \tag{7}$$

The preceding transformation can be carried out only when S is non-singular. When two roots of the Booker quartic are equal, two of the columns $S^{(i)}$ are usually multiples of each other, and then S is singular. Near such points some of the coupling coefficients Γ_{kj} are very large and the points may be points of reflection or points where coupling between two upgoing (or downgoing) waves is very strong. The present program cannot be used in such circumstances.

When the species densities and collision frequencies vary slowly enough with height and where no two of the q_i become nearly equal, the terms of Γ are small quantities and there is an approximate solution for which the non-diagonal elements of Γ are ignored. This solution is associated with one particular root q_j of the Booker quartic. It is [1]

$$f_j = \exp\left(-ik\int^z q_j dz + k\int^z \Gamma_{jj} dz\right) \tag{8}$$

and the corresponding field components [in Budden's notation] are

$$(E_x, E_y, H_x, H_y) = (A_j F_j)^{-1/2}\,(a_3 q_j + a_4, -A_j, q_j A_j, a_5 q_j + a_6)$$
$$\times \exp\left(-ik\int^z q_j dz + k\int^z \Gamma_{jj} dz\right) \tag{9}$$

where

$$a_1 = -(T_{11} + T_{44}) \qquad a_4 = T_{14}T_{42} - T_{12}T_{44}$$

$$a_2 = T_{11}T_{44} - T_{14}T_{41} \qquad a_5 = T_{42} \tag{10}$$

$$a_3 = T_{12} \qquad a_6 = T_{41}T_{12} - T_{11}T_{42}$$

$$A_j = q_j^2 + a_1 q_j + a_2 \tag{12}$$

$$F_j = 2q_j A_j + (q_j^2 - T_{32})(2q_j + a_1) - (a_3 b_5 + b_3 a_5) \tag{13}$$

$$2\Gamma_{jj} = (A_jF_j)^{-1}\{q_j^2\,(a_3b_5' - a_3'b_5 + a_5b_3' - a_5'b_3)$$

$$+ a_4b_6' - a_4'b_6 + a_6b_4' - a_6'b_4 + q_j(a_3b_6' - a_3'b_6 + a_4b_5' - a_4'b_5 + a_5b_4'$$

$$- a_5'b_4 + a_6b_3' - a_6'b_3)\} \qquad (14)$$

In these equations the T_{ij}'s are the elements of the T matrix given by Budden p 389.

The essence of the program documented in this report is the implementation of equation (9) for altitudes exceeding a height termed TOPHT. The mode extracted from the magneto-ionic set is the least attenuated outgoing wave. Full-wave Runge-Kutta integrations are used to calculate the rf field components up to TOPHT. The full-wave solutions at TOPHT are then matched to the corresponding WKB components and the fields carried to higher altitudes via equation (9).

III. EXCITATION FACTORS AND MODE SUMS

Available as output from the present program are excitation factors for sub-ionospheric electric point dipole excitation of electric and magnetic modal fields. They are defined as follows:

$$
\mathrm{EXC}(i,j) = \begin{array}{c} i\backslash j \rightarrow \\ 1 \\ 2 \\ 3 \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \left|\begin{array}{ccc} A_1 & -A_2 & A_1 \\ -A_3 & A_4 & -A_3 \\ -A_1 & A_2 & -A_1 \end{array}\right| \end{array} \tag{15}
$$

$$
\mathrm{MEXC}(i,j) = \begin{array}{c} i\backslash j \rightarrow \\ 1 \\ 2 \\ 3 \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \left|\begin{array}{ccc} -A_2 & A_1 & -A_2 \\ A_4 & -A_3 & A_4 \\ A_2 & -A_1 & A_2 \end{array}\right| \end{array} \tag{16}
$$

where

$$
A_1 = \frac{S^{5/2}\,(1 - {}_{\perp}R_{\perp\,\perp}\bar{R}_{\perp})}{(dF/d\theta \;\, {}_{\parallel}\bar{R}_{\parallel}}; \qquad A_2 = \frac{S^{3/2}\,{}_{\parallel}R_{\perp}}{(dF/d\theta)}
$$

$$
A_3 = \frac{S^{3/2}\,{}_{\perp}R_{\parallel}}{(dF/d\theta)}; \qquad A_4 = \frac{S^{1/2}\,(1 - {}_{\parallel}R_{\parallel\,\parallel}\bar{R}_{\parallel})}{(dF/d\theta)\;\, {}_{\perp}\bar{R}_{\perp}} \tag{17}
$$

In these equations F is the modal function

$$
F = (1 - {}_{\parallel}R_{\parallel\,\parallel}\bar{R}_{\parallel})\,(1 - {}_{\perp}R_{\perp\,\perp}\bar{R}_{\perp}) - {}_{\perp}R_{\parallel\,\parallel}R_{\perp\,\parallel}\bar{R}_{\parallel\,\perp}\bar{R}_{\perp} \tag{18}
$$

and $dF/d\theta$ its derivative with respect to the plane wave angle θ. R and $\bar{R}$ are plane wave reflection coefficients of the ionosphere and ground respectively referenced to level d. Consistent with usual notation, the first subscript refers to the polarization ($\parallel$ for vertical and $\perp$ for horizontal) of the incident wave, and the second subscript applies to the polarization of the reflected wave.

For the purpose of defining field components and mode sums an x, y, z Cartesian coordinate system is assumed with positive z directed vertically upwards into the ionosphere and x measured horizontally, x-z being the plane of incidence. Correspondence between the i,j indices (see equations 15 and 16) and the x, y, z coordinate system is:

$$\begin{aligned} i = j = 1 &\rightarrow z \\ i = j = 2 &\rightarrow y \\ i = j = 3 &\rightarrow x \end{aligned} \tag{19}$$

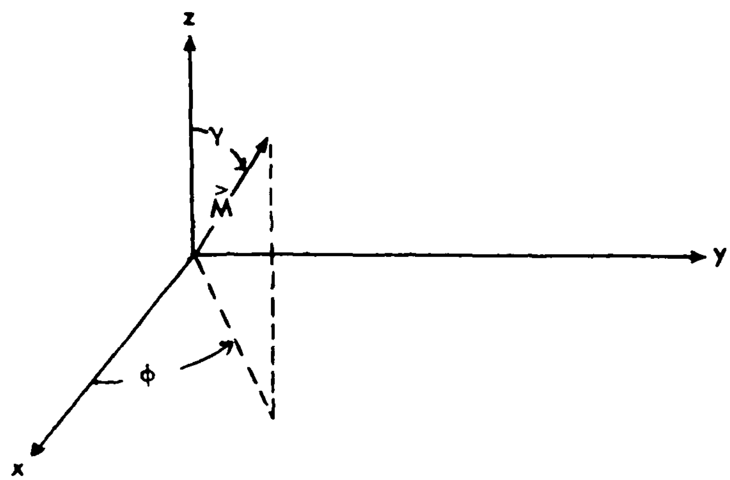
In terms of the excitation factors (EXC(i,j)) the adiabatic (or WKB) mode sums for the total electric field component E_j may be written as

$$\begin{aligned} E_j(x,0,z_R) = \frac{Q_e}{[\sin(x/a)]^{1/2}} \sum_n \{ & (EXC(1,j)^T \; EXC(1,j)^R)_n^{1/2} \cos(\gamma) e_{1n}^T(z_T) \\ & + (EXC(2,j)^T \; EXC(2,j)^R)_n^{1/2} \sin(\gamma) \sin(\phi) e_{2n}^T(z_T) \\ & + (EXC(3,j)^T \; EXC(3,j)^R)_n^{1/2} \sin(\gamma)\cos(\phi) e_{3n}^T(z_T)\} \\ & e_{jn}^R(Z_R) e^{-ik(Sn-1)x} \end{aligned} \tag{20}$$

where the subscript n denotes the mode index, a the earth's radius, k the free space wave number and S the sine of the ground eigenangle. The transmitter is at $(0, 0, z_T)$ and the receiver is at $(x, 0, z_R)$. The components of the electric field height gain are denoted by the e_j's and the superscripts T and R signify that the quantities are to be evaluated for the transmitter or receiver regions respectively. With the frequency f in kHz, the radiated power P in kW and

$$Q_e = 6.803 \times 10^2 \, (f_{kHz} \, P_{kW})^{1/2} \tag{21}$$

the total field component, E_j, is in units of $\mu V/m$. The angles γ and ϕ measure the orientation of the transmitting dipole relative to the x, y, z coordinate system as shown



In similar fashion the mode sums for the components of the total magnetic induction, B_j, may be written as follows

$$B_j(x,0,z_R) = \frac{Q_b}{[\sin(x/a)]^{1/2}} \sum_n \{(MEXC(1,j)^T MEXC(1,j)^R)_n^{1/2} \cos\gamma \; e_{1n}^T(z_T)$$

$$+ (MEXC\ (2,j)^T MEXC(2,j)^R)_n^{1/2} \sin\gamma \sin\phi \; e_{2n}^T(z_T) + (MEXC\ (3,j)^T$$

$$MEXC\ (3,j)^R)_n^{1/2} \sin\gamma \sin\phi \; e_{3n}^T\ (z_T)\} h_{jn}^R(z_R)\ e^{-ik(S_n-1)\ x} \tag{22}$$

The components of the magnetic field height gain are denoted by the h_j's. With

$$Q_b = 7.176 \times 10^{-2}\ (f_{kHz}\ P_{kw})^{1/2} \tag{23}$$

the total field component, B_j, is in units of γ ($1\gamma = 10^{-5}$ gauss $= 10^{-9}$ W/m^2).

Although the transmitter altitude z_T must be in the isotropic portion of the guide beneath the ionosphere, the receiver altitude z_R in equation (20) or (22) can be within the earth-ionosphere waveguide or within the ionosphere itself. The program can, then, be used to generate required inputs for studies such as satellite reception of ground based VLF transmission using waveguide concepts [4]. Apart from impedance considerations the program can be used in conjunction with general magneto-ionic reciprocity theory [9] to estimate fields radiated into the earth-ionosphere waveguide by satellite-borne sources. However, more direct means are available for making that type of calculation [3] and it is recommended that the WKB method employed here be implemented directly into the program of reference [3].

In past work [2] the electric and magnetic field modal height gains have been normalized by equating the y component of the magnetic field to unity at the ground. We will denote the electric and magnetic field components so normalized by $\bar{e}_i$ and $\bar{h}_i$. These quantities are printed out in the current program under the listing "HEIGHT GAINS WITH HY NORMALIZED TO UNITY AT THE GROUND." The height gains e_i and h_i entering equations (20) and (22) are related to $\bar{e}_i$ and $\bar{h}_i$ as follows:

$$e_1 = (1 + {}_{\parallel}\bar{R}_{\parallel})\, \bar{e}_1/\bar{e}_1(d)$$

$$e_2 = (1 + {}_{\perp}\bar{R}_{\perp})\, \bar{e}_2/\bar{e}_2(d)$$

$$e_3 = (1 + {}_{\parallel}\bar{R}_{\parallel})\, \bar{e}_3/\bar{e}_1(d)$$

; barred quantities are height gain components normalized with $\bar{h}_2 = \bar{h}_y = 1$ at the ground. (24)

$$h_1 = (1 + {}_{\perp}\bar{R}_{\perp})\, \bar{h}_1/\bar{e}_2(d)$$

$$h_2 = (1 + {}_{\parallel}\bar{R}_{\parallel})\, \bar{h}_2/\bar{e}_1(d)$$

$$h_3 = (1 + {}_{\perp}\bar{R}_{\perp})\, \bar{h}_3/\bar{e}_2(d)$$

The height gains e_i and h_i are calculated and printed when excitation factor data are requested (ie, when IEXC.NE.0). They are printed out under the label "HEIGHT GAINS NORMALIZED FOR USE WITH WKB MODE SUMMING FORMULAS."

It is these unbarred height gains which must be used in conjunction with the excitation factors defined by equations (15) and (16) in the mode summing formulas (20) and (22). The level d in equation (24) is the level where the mode equation is evaluated and is equivalent in the program to LWSTHT.

IV. PROGRAM DESCRIPTION

This section describes the subroutines in the WKBHTG program listed in the appendix. Many of the subroutines are only slight modifications of those given in reference [2]. The subroutines WKBVAR, QGAMMA and DDKXMT have been added for the purpose of implementing the WKB formalism. Principal output of the program is height gain functions. Height gains with two different normalizations are available. The first, which is always calculated, printed and plotted, is printed under the heading "HEIGHT GAINS NORMALIZED WITH HY EQUAL TO UNITY AT THE GROUND." This normalization is consistent with past works [2,3,5]. The second set of height gains is calculated and printed only when excitation factor data are requested (ie, when IEXC .NE. 0). This second set of height gains is printed out under the heading "HEIGHT GAINS NORMALIZED FOR USE WITH WKB MODE SUMMING FORMULAS," and defined by equations (24) of section III. Also printed out when IEXC .NE. 0 are the excitation factors defined by equations (15), (16) and (17) of section III. The second set of height gains must be used in conjunction with the excitation factors when implementing the WKB mode summing formulas (20) and (22). A chart showing the essential structure of the WKB height gain program follows on pages 19 through 22.

SUBROUTINE MAIN

MAIN calls for the input of ionic species data in XINPUT and for computation of height gain field components via WAVFLD. After executing WAVFLD, height gains are available in the arrays EX, EY, EZ, HX, HY, and HZ at DELHT intervals between the ground and WKBHT. If IEXC .EQ. 0, the height gains available in the arrays are those associated with HY normalized to unity at the ground. Otherwise the height gains available in the arrays are those renormalized according to equations (24).

SUBROUTINE XINPUT (ISTART, ISTOP)

XINPUT controls read-in of input parameters via NAMELIST statements and ionic species densities and collision frequencies as a function of altitude. Common areas are set up as required. ISTART is set to 1 before the first call to XINPUT and to 0 upon subsequent calls. ISTART = 1 implies all necessary data are to be read in and ISTART = 0 signals that previously read data are to be updated, with all unspecified parameters remaining unchanged. If a value ISTOP = 0 is returned by XINPUT, then more input data are specified in the data deck for subsequent calls to WAVFLD, whereas if a value ISTOP = 1 is returned, the data read were the last data in the data deck, so that XINPUT should not be called again.

The data deck is divided into several parts, each of which is marked by an identifier card with the identifier DATUMFOL, SPECIE, PROFILE, COLLFREQ, QUIT or STOP. Each of these identifiers is described in the following section.

SUBROUTINE WAVFLD (EX, EY, EZ, HX, HY, HZ)

WAVFLD calls for Runge-Kutta integration of the field equations from TOPHT to LWSTHT at DELHT equally spaced increments and for combining the solutions at LWSTHT so that they satisfy the proper modal polarization condition. It performs the back substitution of normalizing values (saved as data in WFSTOR). It also calls for calculation of height gains between the ground and LWSTHT at DELHT increments via modified Hankel functions of order one-third as well as the extension of height gain functions from TOPHT to WKBHT via Budden's WKB formalism (these height gains are normalized with HY = 1 at the ground and are always printed out). If IEXC.NE.0 it also calls for calculation of the excitation factors defined in section III and renormalization of the height gains according to equations (24). Upon exiting, WAVFLD places the field strengths in the arrays EX, EY, EZ, HX, HY HZ at DELHT intervals between the ground and WKBHT. If IEXC .EQ. 0, the height gains available in the arrays are those associated with HY normalized to unity at the ground. Otherwise the height gains in the arrays are those renormalized according to equations (24).

SUBROUTINE ITRATE

ITRATE is the control routine for finding an angle, theta, which satisfies the modal equation. It calls for integration through the ionosphere (WFINTG), and for R, $\bar{R}$ and modal function evaluations a variable number of times depending upon whether iteration of the input angle is desired (ie, ITR.NE.0) and whether excitation factors are desired (ie, IEXC.NE.0).

SUBROUTINE WFINTG (TOPHT, LWSTHT, DELHT, IFLAG)

WFINTG performs the Runge-Kutta integration of the two solution vectors in P down through the ionosphere. Numerical solutions are obtained at all height increments of DELHT between TOPHT and LWSTHT. Accuracy is maintained by continually adjusting the step size used in the numerical integration. The current step size (call it h) is used to obtain an estimate of P, and then a better estimate is obtained by using two integrations with step size h/2. If the two solutions agree within an error of PRECSN (an input parameter normally set to 3.D-5), the better estimate is accepted. The step size is automatically decreased to h/2 if the two estimates differ by more than PRECSN, and the integration is repeated. If the error is significantly greater than PRECSN, a step size h/2 is used. If the error is significantly less than PRECSN, the step size 2h is used if it also yields an error less than PRECSN. These tests thus form an automatic step-size correction. IFLAG is an internally controlled flag. If IFLAG = 0 the integration is performed for THETA only, if IFLAG = 1 the integration is performed for THETA and THETA-DTHETA where DTHETA is internally set to (5.D-2, 1.D-2).

ENTRY INIT T

INIT T is an entry in subroutine TMTRX. Sets up height independent values to be used in T matrix calculation. These include the internally set flag ISO (ISO = 1 for isotropic calculation, 0 otherwise). Also set are the angular radio frequency, the wave number, direction cosines of the geomagnetic field, the complex sine and cosine of THETA and THETA-DTHETA.

SUBROUTINE TMTRX(HT)

TMTRX computes the value of the T matrix at a specific height HT. The T matrix depends upon input ionospheric parameters (species density, collision frequency, angle of propagation, magnetic field, etc). The susceptibility

matrix, M, for each species in the ionosphere is computed, the effect of earth curvature is included and the T matrix is computed from the susceptibility matrix elements. The equations used to evaluate the M and T are given in Clemmow and Heading [8] and by Budden [1].

SUBROUTINE WFDENS

WFDENS (HT, EN, COLL) computes the species density (returned in EN) and collision frequencies (returned in COLL) at height HT for up to five species in the ionosphere. EN and COLL are determined from corresponding profiles in the common field WFPROF. LHT and MHT are integer values which indicate which profile values are to be interpolated to find values at the height HT. The EN (or COLL) values are given by logarithmic interpolation of the profile values at heights ENHT(LHT + 1) and ENHT(LHT) or (COLLHT(MHT + 1) and COLLHT(MHT),).

SUBROUTINE WF INIT(P)

WF INIT computes the two starting field vectors in P at TOPHT subject to the condition of outgoing wave. This is done by making use of Booker quartic solutions for a homogeneous anisotropic medium.

SUBROUTINE QUARTC (FOUR B3, SIX B2, FOURB1, BO,Q)

QUARTC computes the four roots of the polynomial Q^4+FOURB3*Q^3 + SIXB2*Q^2 FOURB1*Q + BO in closed form [10]. Up to ten applications of Newton's iteration are then performed to improve the accuracy of the roots, if necessary.

SUBROUTINE PDERIV(P,DPDH)

PDERIV computes the height derivatives of the two field vectors in P according to Clemmow and Heading [8]. The derivative is returned in DPDH.

ENTRY TI MTRX

This is an entry in TMTRX which calculates T matrix elements for the incremental plane wave angle THETA-DTHETA.

SUBROUTINE XFER (A,B,N)

Transfers the N element array A into B.

ENTRY WF STOR

WF STOR is an entry in WFSCAL where certain values obtained during integration through the ionosphere are saved for later use. The solution matrix P, the height for which P is a solution and a height integer index are saved along with orthogonalization and normalization values OSUM, APROD and BPROD. In addition, values of the susceptibility matrix elements M31, M32 and M33, which are needed to compute the EZ component of the electric field, are saved at each height.

SUBROUTINE WF STEP (P,DPDH, HT, DELHT, IFLAG)

WF STEP numerically advances the solution matrix P, using the derivative DPDH, from HT to HT-DELHT by the Runge-Kutta method. IFLAG, set internally, controls the calculations at intermediate points between HT and HT-DELHT at which evaluations are required for comparison of the second and fourth order Runge-Kutta integrations.

SUBROUTINE WF SCAL (PP, IFLAG)

WF SCAL normalizes and orthogonalizes the solution vector PP according to the formulas of reference [2]. This scaling must later be removed to yield correct unscaled solutions. Control for calculating the quantities needed for removal of the scaling is the internally set IFLAG. The quantities OSUM, APROD and BPROD needed in the backward substitution (or equivalently for removing the scalings) are calculated for IFLAG = 0.

ENTRY FFCT (PP, C, S, F)

This is an entry in WF BNDY which evaluates the mode function:

$$F = (1 - {}_{\parallel}R_{\parallel}\ {}_{\parallel}\overline{R}_{\parallel})\ (1 - {}_{\perp}R_{\perp}\ {}_{\perp}\overline{R}_{\perp}) - {}_{\perp}R_{\parallel}\ {}_{\parallel}R_{\perp}\ {}_{\parallel}\overline{R}_{\parallel}\ {}_{\perp}\overline{R}_{\perp}$$

The two field solution vectors given in PP along with cosine (C) and sine (S) of the plane wave incident angle THETA are used in computing the reflection coefficients by plane wave decomposition at LWSTHT.

SUBROUTINE RMTRX (P, COSN, R)

RMTRX computes the 2 x 2 ionospheric reflection coefficient matrix (returned in R) from the two solution vectors given in P. The two solutions at LWSTHT are transformed into upgoing and downgoing components and the ratio of these components determines the reflection coefficients.

SUBROUTINE RBARS(C,S,RBAR11, RBAR22, EY, HY)

RBARS calculates the plane wave reflection coefficients (returned in RBAR11 and RBAR22) looking towards the ground from LWSTHT. Evaluations are in terms of modified Hankel functions of order 1/3. The cosine (C) and sine (S) of the plane wave angle THETA are used in the $\overline{R}$ determination. Note that RBAR11 $\doteq {}_{\parallel}\overline{R}_{\parallel}$ and RBAR22 $\doteq {}_{\perp}\overline{R}_{\perp}$.

SUBROUTINE MDHNKL (Z, H1, H2, H1PRME, H2PRME)

MDHNKL calculates for argument Z two independent solutions (H1 and H2) and their derivatives (HIPRME, H2PRME) of Stokes' equation by methods described in reference [11].

SUBROUTINE WF BNDY(B)

WF BNDY computes the coefficients B_1, B_2 (in B) which are used to linearly combine the two solutions in P to form the unique solution which satisfies the boundary condition on the modal polarization at LWSTHT and the normalization condition HY = 1 at Z = 0. The polarization condition is:

$$EY/HY = \frac{1 + {}_{\perp}\overline{R}_{\perp}}{1 + {}_{\parallel}\overline{R}_{\parallel}} \; \frac{(1 - {}_{\parallel}R_{\parallel}\, {}_{\parallel}\overline{R}_{\parallel})}{{}_{\perp}R_{\parallel}\, {}_{\perp}\overline{R}_{\perp}} = \frac{1 + {}_{\perp}\overline{R}_{\perp}}{1 + {}_{\parallel}\overline{R}_{\parallel}} \; \frac{{}_{\parallel}R_{\perp}\, {}_{\parallel}\overline{R}_{\parallel}}{1 - {}_{\perp}R_{\perp}\, {}_{\perp}\overline{R}_{\perp}}$$

where all reflection coefficients are referenced to LWSTHT.

ENTRY HT GAIN (ALTT, EX, EY, EZ, HX, HY, HZ)

HT GAIN is an entry in RBARS where the field height gains at heights ALTT between the ground and LWSTHT are calculated at DELHT intervals using modified Hankel functions of order 1/3.

ENTRY WF LOAD

WF LOAD is an entry in WFSCAL which transfers normalizing and orthogonalizing values saved in WFSTOR for the purpose of unscaling the two solutions in P starting from LWSTHT and proceeding to TOPHT at DELHT intervals.

SUBROUTINE WKBVAR (EX, EY, EZ, HX, HY, HZ)

WKBVAR extends calculation of the field equations from TOPHT to WKBHT by means of the formulas in section II. Integration of the phase factors q_j and Γ_{jj} (j index for least attenuated outgoing mode) is performed by a Simpson rule routine which maintains precision by adjustment of the step size much like the Runge-Kutta step size adjustment in WFINTG.

ENTRY INITDT

This is an entry in DDKXMT where all height independent quantities are initialized before extending field calculations from TOPHT to WKBHT via the WKB method.

SUBROUTINE Q GAMMA (HT, DELHT, TOPHT, Q, GAMMA)

Q GAMMA determines the Booker quartic solution for the least attenuated outgoing magneto-ionic component at TOPHT and computes the a_i's, b_i's, a_i''s, b_i''s, A_i, F_i and Γ_{ii} according to formulas of section II. Full-wave solutions are matched at TOPHT to the WKB solutions. At other heights and up to WKBHT coefficients of the exponentials in equation (9) of section II are calculated along with coefficients for HZ and EZ.

SUBROUTINE DDKXMT

DDKXMT calculates susceptibility matrix elements, M, the T matrix elements and their derivatives with respect to height in the height range TOPHT $\leq$ Z $\leq$ WKBHT.

ENTRY EXCFAC(S)

EXCFAC is an entry in WFBNDY where the excitation factors for the sine (S) of the plane wave eigenangle THETA are calculated according to the formulas of section III.

MAIN

Calls for input data via XINPUT, computation of height gain functions (with HY=1 at the ground), excitation factors (if IEXC .NE. 0) along with renormalized height gains (if IEXC.NE.0) by WAVFLD.

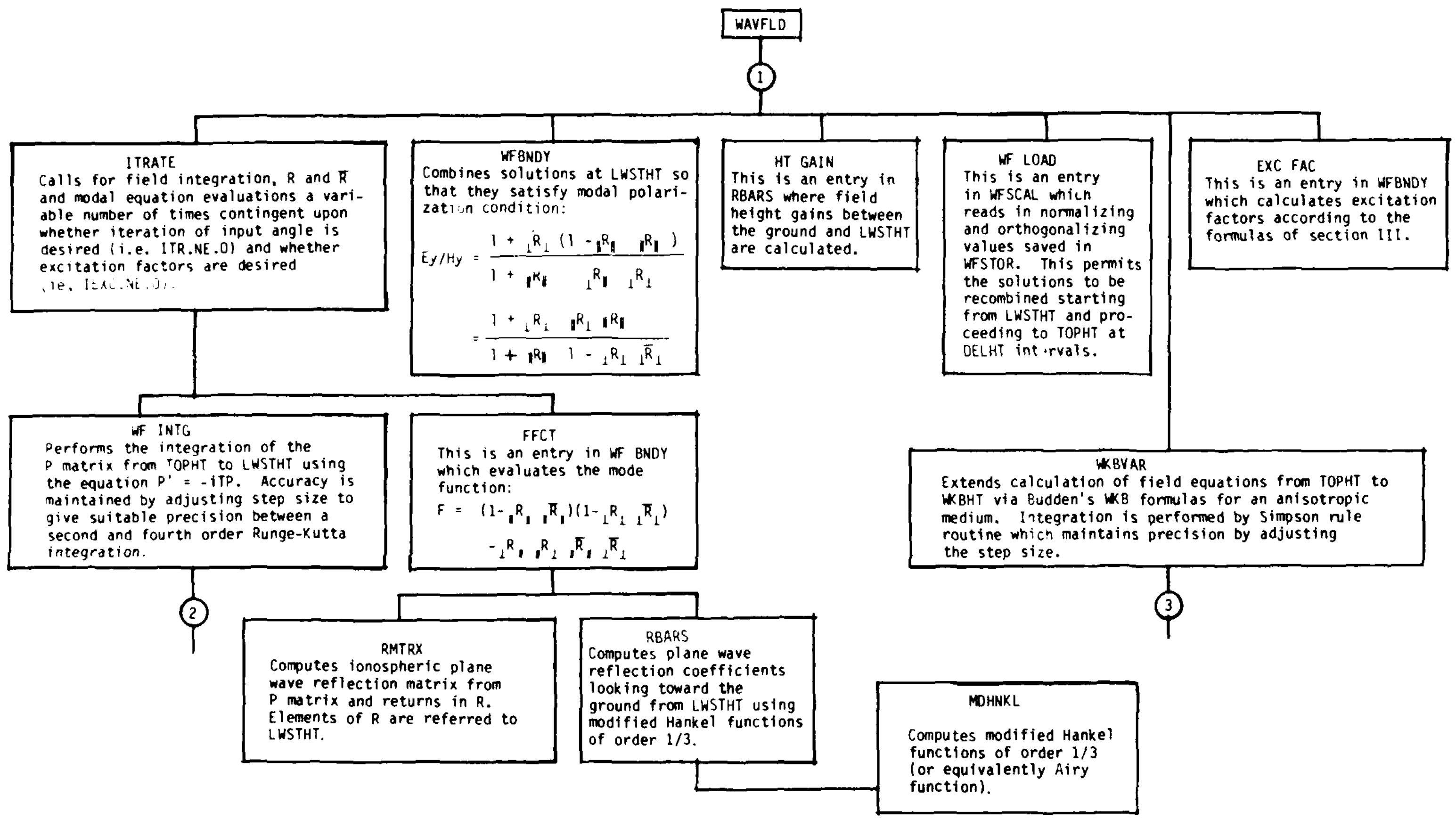
XINPUT

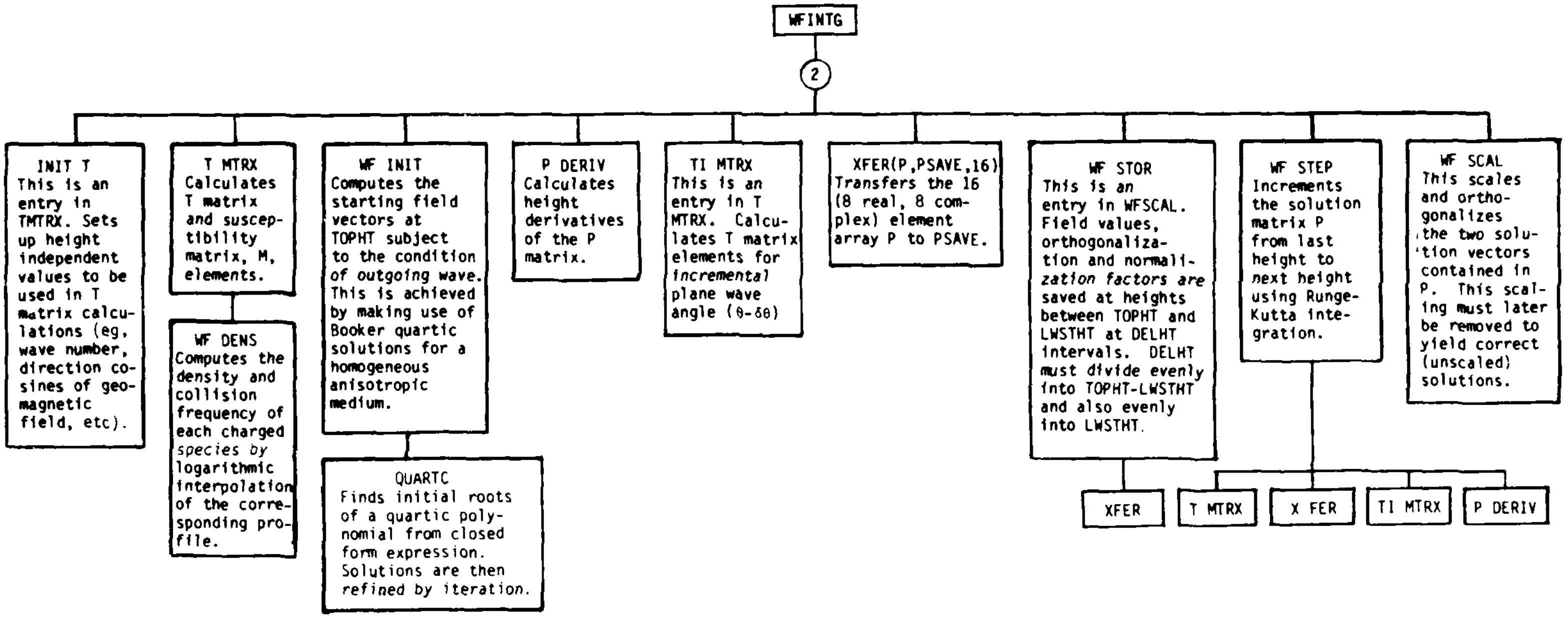
Input electron and ion species densities and collision frequencies as a function of altitude.

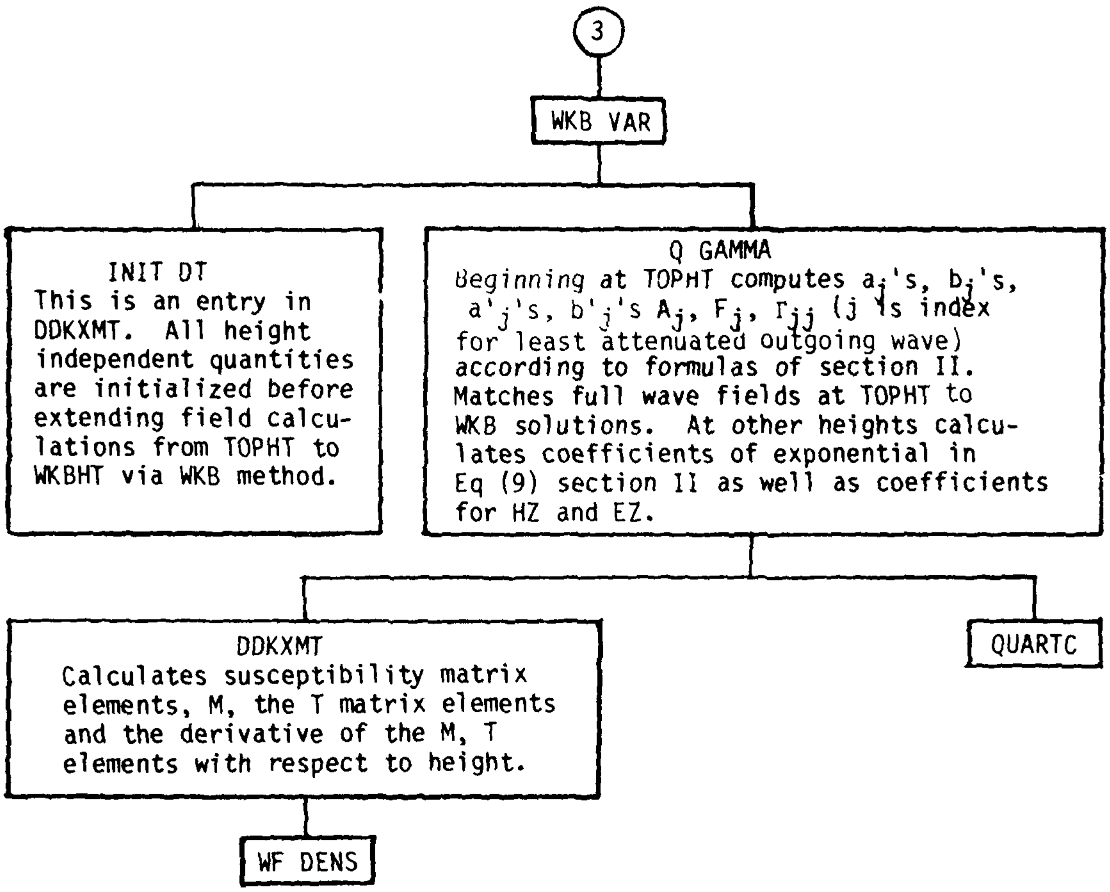
WAVFLD

Calls for Runge-Kutta integration of the field equations from TOPHT to LWSTHT at DELHT increments and for combining solutions at LWSTHT so that they satisfy the proper modal polarization conditions. It performs the back substitution of normalizing values (saved as data in WFSTOR). It also calls for calculation of height gains between the ground and LWSTHT at DELHT increments via modified Hankel functions of order 1/3 as well as the extension of height gain functions from TOPHT to WKBHT via Budden's WKB formalism. These height gains are normalized with HY=1 at the ground. Lastly, if IEXC.NE.0 WAVFLD calls for calculation of excitation factors and height gains normalized according to Eqs (24).

1


WAVFLD
1
ITRATE
Calls for field integration, R and R̄ and modal equation evaluations a variable number of times contingent upon whether iteration of input angle is desired (i.e. ITR.NE.0) and whether excitation factors are desired (ie, IEXC.NE.0).
WFBNDY
Combines solutions at LWSTHT so that they satisfy modal polarization condition:
HT GAIN
This is an entry in RBARS where field height gains between the ground and LWSTHT are calculated.
WF LOAD
This is an entry in WFSCAL which reads in normalizing and orthogonalizing values saved in WFSTOR. This permits the solutions to be recombined starting from LWSTHT and proceeding to TOPHT at DELHT intervals.
EXC FAC
This is an entry in WFBNDY which calculates excitation factors according to the formulas of section III.
WF INTG
Performs the integration of the P matrix from TOPHT to LWSTHT using the equation P' = -iTP. Accuracy is maintained by adjusting step size to give suitable precision between a second and fourth order Runge-Kutta integration.
2
FFCT
This is an entry in WF BNDY which evaluates the mode function:
WKBVAR
Extends calculation of field equations from TOPHT to WKBHT via Budden's WKB formulas for an anisotropic medium. Integration is performed by Simpson rule routine which maintains precision by adjusting the step size.
3
RMTRX
Computes ionospheric plane wave reflection matrix from P matrix and returns in R. Elements of R are referred to LWSTHT.
RBARS
Computes plane wave reflection coefficients looking toward the ground from LWSTHT using modified Hankel functions of order 1/3.
MDHNKL
Computes modified Hankel functions of order 1/3 (or equivalently Airy function).


WFINTG
2
INIT T
This is an entry in TMTRX. Sets up height independent values to be used in T matrix calculations (eg, wave number, direction cosines of geomagnetic field, etc).
T MTRX
Calculates T matrix and susceptibility matrix, M, elements.
WF DENS
Computes the density and collision frequency of each charged species by logarithmic interpolation of the corresponding profile.
WF INIT
Computes the starting field vectors at TOPHT subject to the condition of outgoing wave. This is achieved by making use of Booker quartic solutions for a homogeneous anisotropic medium.
QUARTC
Finds initial roots of a quartic polynomial from closed form expression. Solutions are then refined by iteration.
P DERIV
Calculates height derivatives of the P matrix.
TI MTRX
This is an entry in T MTRX. Calculates T matrix elements for incremental plane wave angle (θ-δθ)
XFER(P,PSAVE,16)
Transfers the 16 (8 real, 8 complex) element array P to PSAVE.
WF STOR
This is an entry in WFSCAL. Field values, orthogonalization and normalization factors are saved at heights between TOPHT and LWSTHT at DELHT intervals. DELHT must divide evenly into TOPHT-LWSTHT and also evenly into LWSTHT.
XFER
WF STEP
Increments the solution matrix P from last height to next height using Runge-Kutta integration.
T MTRX
X FER
TI MTRX
P DERIV
WF SCAL
This scales and orthogonalizes the two solution vectors contained in P. This scaling must later be removed to yield correct (unscaled) solutions.


3
WKB VAR
INIT DT
This is an entry in DDKXMT. All height independent quantities are initialized before extending field calculations from TOPHT to WKBHT via WKB method.
Q GAMMA
Beginning at TOPHT computes a_j's, b_j's, a'_j's, b'_j's A_j, F_j, Γ_{jj} (j is index for least attenuated outgoing wave) according to formulas of section II. Matches full wave fields at TOPHT to WKB solutions. At other heights calculates coefficients of exponential in Eq (9) section II as well as coefficients for HZ and EZ.
DDKXMT
Calculates susceptibility matrix elements, M, the T matrix elements and the derivative of the M, T elements with respect to height.
QUARTC
WF DENS

V. SAMPLE INPUT AND OUTPUT

A. INPUT

Altitude independent parameters, species densities and collision frequencies as a function of altitude are supplied via an input data deck on a standard input unit. Read-in occurs in the subroutine XINPUT. The data deck is divided into several parts, each of which is marked by control cards DATUMFOL, SPECIE, PROFILE, COLLFREQ, QUIT, or STOP. Each of these control cards is described below:

i) DATUMFOL

DATUMFOL - is a control card signifying that input for the namelist DATUM follows.

&DATUM - initiates reading of altitude independent input data in namelist input format. These data are:

THETA - complex angle of incidence in degrees as measured at H.THETA must be an eigenangle if ITR = 0.

FREQ - frequency in kHz.

IDBG - integer flag controlling auxiliary printout. If IDBG.GE.1, the R matrix elements, ${}_{\parallel}\bar{R}_{\parallel}$ and ${}_{\perp}\bar{R}_{\perp}$, are printed. If IDBG.GE.2 the solution vectors (P) at TOPHT and LWSTHT are printed along with the Booker quartic solution at TOPHT and the combining coefficients (B(1), B(2)) of the two independent solution vectors contained in P at LWSTHT.

TOPHT - starting height for full-wave integration (km).

LWSTHT - lowest height for full-wave integration (km). Also equivalent to level D where mode equation is evaluated.

WKBHT - altitude in km to which height gains are extended beyond TOPHT via WKB formulas.

DELHT - height increment in km at which height gains are printed.

PRECSN - accuracy to be maintained locally in the numerical integrations. Usually taken to be the default value of 3.0E-5.

AZIM - azimuth of propagation path in degrees, measured clockwise from geomagnetic north.

CODIP - codip of geomagnetic field in degrees

MAGFLD - geomagnetic field strength in webers/square meter

COEFNU(5)
EXPNU(5) - coefficient and exponent of exponential form of collision frequency (if not specified by profile). Up to five values may be specified, one for each species.

ALPHA - earth curvature coefficient in inverse km. Default is 3.14E-4.

SIGMA - ground conductivity in siemens/meter. Default value is the seawater value of 4.64.

EPSLON - ground permittivity in farads/meter. Default value is 7.172015D-10. This corresponds to a

dielectric constant of 81 for seawater.

ISO - flag signaling whether calculations are to be performed for isotropic or anisotropic ionosphere. ISO.NE.0 signals isotropy.

ITR - integer flag which calls for modal equation iteration when ITR .NE. 0.

H - altitude in km at which modified refractive index is unity. Eigenangles are referenced to this altitude.

&END - signifies end of the DATUM namelist input.

ii) SPECIE

SPECIE - is a control card signifying that input for namelist SPECIE follows.

&SPECIE - initiates reading of altitude independent species data. These data are:

NRSPEC - number (integer) of species in the ionosphere. Can take on values up to 5. Default value is 1.

CHARGE(5) - sign of charge of each species in proton units. For an electron, the CHARGE is -1.0. Default values are -1.0, 1.0, -1.0, 1.0, -1.0).

RATIOM(5) - mass of each species relative to mass of an electron. Default values are (1.0, 5.8D4, 5.8D4, 5.8D4, 5.8D4).

&END - signifies the end of the SPECIE namelist input.

iii) PROFILE

PROFILE - is a control card initiating reading of the ionospheric profile cards. The control card PROFILE is followed by an alpha-numeric card which is used to identify the profile. The profile is input starting at the top of the ionosphere. The cards must be input in descending order by height. The profile cards contain the height in kilometers and the species densities in particles per cubic centimeter. A maximum of five species can be specified. In the special case of three species, only two are specified on the card. The first is assumed to be electrons and the second is positive ions. The third species, negative ions, is calculated by subtracting the electron density from the positive ion density. All three species are listed on the computer printout. If the value of any species density is less than or equal to zero, it is set in the program to 1.0E-40. The heights are punched in the form XXX.XX with the decimal point in column 5, and the densities are punched in the form X.XXD±XX with the decimal points in column 15, 25, etc. All species data must be specified except for the special case discussed above. The end of the profile is indicated by a dummy height of 999.99.

iv) COLLFREQ

COLLFREQ - is a control card initiating reading of the collision frequency profile. This allows using non-exponential collision frequencies. A strictly exponential collision frequency may be specified in namelist input by the variables COEFNU and EXPNU.

If a profile deck is used it overrides COEFNU and EXPNU. Collision frequencies for all species must be input. The card preparation is just as above with species density values replaced by collision frequency values (in collisions/s) on the cards.

v) QUIT

QUIT - is a card control which indicates the end of input data for a call to WAVFLD. After calling WAVFLD, XINPUT can be read and used as data for a subsequent call to WAVFLD. This allows several runs to be made with one input deck. Note that only those data which are changed need be specified after the card QUIT.

vi) STOP

STOP - control card which indicates that there are no more input data and that the run is to be terminated after the next call to WAVFLD. Note that if QUIT is encountered ISTOP is set to zero, but if STOP is encountered ISTOP is set to one.

A schematic of an input deck is shown on page 30 , and an actual sample input is shown on pages 31 and 32.

B. OUTPUT

The output corresponding to the input is shown on pages 33 through 51. The output corresponds to the flag settings ITR .EQ. 1 and IEXC .EQ. 1.

First come NAMELIST and profile printouts followed by output, which gives the number of Runge-Kutta integration steps used in WAVFLD during the course of integrating from TOPHT to LWSTHT. This is followed by the modal equation values for the input eigenangle THETA shown on page 35. Since ITR.EQ.1 an

iteration is performed and the iterated value of THETA is shown as NEW THETA on the output. The process of integration from TOPHT to LWSTHT is repeated for this NEW THETA. Again the number of integration steps and modal equation value is shown. The iteration stops because the change in the absolute value of the real part of the eigenangle is .LE. 5.D-2 and the change in the absolute value of the imaginary part is .LE. 5.D-3.

The first set of field strengths at 50.0 km (LWSTHT) is calculated using ground boundary conditions and modified Hankel functions of order one-third to extend the calculations to 50. km. The second set is calculated from the Runge-Kutta field integration. Together the two sets of field strengths give an alternative check of how well the modal condition is satisfied. This alternative check is particularly useful when ITR .NE. 0 and eigenangles are input from another program such as the waveguide program of reference [12]. It has been our experience that a good eigenangle will cause the two sets of field values to agree to better than one percent.

Since IEXC .EQ. 1 the excitation factors EXC(I,J) and MFXC(I,J) defined in section III are calculated and printed. The rows correspond respectively to electric dipole excitation produced by a vertical (V), horizontal broadside (HB), and horizontal end-on (HE) oriented dipole. The columns are for excitation of the EZ (or HZ), EY (or HY) and EX (or HX) components. That is to say EXC(I,J) and MEXC(I,J) are to be combined with height gain components according to the mode summing formulas of section III.

Following the excitation factors come the height gains calculated at DELHT intervals up to WKBHT. They are normalized with HY = 1 at the ground. This is consistent with past work [2,5]. The magnitudes of these height gains are also plotted and the plot is shown on page 52. The rapid change in the slope of the EY, EZ, and HZ plots is quite surprising. An immediate reaction might be that this is where the full-wave and WKB fields are matched. However, though unexplained, the break ($\simeq$ 94 km) is much too low (TOPHT = 120 km) and totally unrelated to field matching at TOPHT. Consistency of the full-wave calculations, as indicated by the modal function evaluation and the continuity of the field components at LWSTHT along with the fact that, as indicated in the following section, the fullwave and WKB methods yield nearly identifical results for fields above TOPHT, points towards the accuracy of the full-wave methods. It is clear that very little of the EY, EZ and HZ

components penetrate the ionosphere for the first order mode used for the sample input. Penetration is greater the higher the order of the mode. Finally, the large value of the relative fields within the guide is peculiar to the low conductivity (10^{-5} S/M) indicated in the sample input. Because IEXC .NE. 0 a second set of height gains normalized according to Equations (24) are calculated. These are the height gains that are to be used in conjunction with the excitation factors EXC(I,J) and MEXC(I,J) in the WKB mode summing formulas (20) and (22).

EXAMPLE OF INPUT DECK

```
DATUMFØL

&DATUM
(input data)
&END

SPECIE

&SPECIE
(input specie data)
>END

PRØFILE

(profile cards for each specie)

999.99

CØLLFREQ

(coll. frequency cards for each specie)

999.99

QUIT (end of input for this run)

DATUMFØL

&DATUM
(changes in input data)
&END

PRØFILE

(specify entire new profile deck)

999.99

QUIT (end of input for this run)

DATUMFØL

&DATUM
(changes in input data)
&END

STØP (end of data deck)
```

SAMPLE INPUT

```
DATUMFOL
 &DATUM
  FREQ = 17.8,
  COEFNU = .1816D12, EXPNU = -.15D-3,
  AZIM = 87.801, CODIP = 6.593, MAGFLD = .5222D-4,
  SIGMA = 1.D-5,EPSLON = .442717D-10,
  ALPHA = 3.14D-4,
  PRECSN = 3.D-5,
  THETA = (89.89694661,-4.96306701),
  ITR = 1,
  IEXC = 1,
  TOPHT = 120.,LWSTHT = 50., WKBHT = 500.,DELHT = 5.,
  &END
PROFILE 1
GLOBAL NIGHTTIME IONOSPHERE(SAT. NIGHT ABOVE 99, H' = 87 BELOW 99)
  500.00      2.00+005
  400.00      4.00+005
  370.00      4.30+005
  350.00      4.40+005
  330.00      4.30+005
  250.00      1.00+005
  225.00      5.00+003
  220.00      3.20+003
  210.00      1.68+003
  200.00      1.00+003
  190.00      6.50+002
  180.00      4.60+002
  170.00      3.45+002
  160.00      2.82+002
  155.00      2.60+002
  150.00      2.50+002
  145.00      2.55+002
  140.00      2.80+002
  130.00      3.70+002
  120.00      5.80+002
  112.00      1.10+003
  110.00      1.30+003
  106.00      1.70+003
  104.00      1.90+003
  102.00      1.98+003
  100.00      2.00+003
   99.00      1.95+003
     .00      1.83-012
  999.99
COLLFREQ
  500.00      2.00+002
  400.00      3.80+002
  370.00      3.90+002
  350.00      3.80+002
  330.00      3.50+002
  300.00      2.80+002
  250.00      1.05+002
  225.00      3.50+001
  220.00      3.00+001
```

SAMPLE INPUT

```
  210.00    3.30+001
  200.00    4.50+001
  150.00    1.60+003
  120.00    1.00+004
  104.00    3.00+004
    0.00    1.82+011
  999.99
 STOP
```

SAMPLE OUTPUT

```
DATUMFOL
 $DATUM
THETA =( .89896946610000000+002,-.49630670099999999+001),FREQ = .17800000000000000+002,IDBG =          0,
TOPHT = .12000000000000000+003,LWSTHT = .50000000000000000+002,WKBHT = .50000000000000000+003,DELHT = .50000000000000000+001,
PRECSN = .30000000000000000-004,AZIM = .87800999999999999+002,CODIP = .65930000000000000+001,MAGFLD = .52219999999999999-004,
COEFNU = .18160000000000000+012, .000000000000000000    , .000000000000000000    , .000000000000000000    , .000000000000000000
EXPNU =-.15000000000000000-003, .000000000000000000    , .000000000000000000    , .000000000000000000    , .000000000000000000
ALPHA = .31400000000000000-003,SIGMA = .10000000000000000-004,EPSLON = .44271699999999999-010,ISO =          0,
IEXC =          1,ITR =          1,H = .000000000000000000
$END
PROFILE 1
GLOBAL NIGHTTIME IONOSPHERE(SAT. NIGHT ABOVE 99, H' = 87 BELOW 99)
 500.00      2.00+005
 400.00      4.00+005
 370.00      4.30+005
 350.00      4.40+005
 330.00      4.30+005
 250.00      1.00+005
 225.00      5.00+003
 220.00      3.20+003
 210.00      1.68+003
 200.00      1.00+003
 190.00      6.50+002
 180.00      4.60+002
 170.00      3.45+002
 160.00      2.82+002
 155.00      2.60+002
 150.00      2.50+002
 145.00      2.55+002
 140.00      2.80+002
 130.00      3.70+002
 120.00      5.80+002
 112.00      1.10+003
 110.00      1.30+003
 106.00      1.70+003
 104.00      1.90+003
 102.00      1.98+003
 100.00      2.00+003
  99.00      1.95+003
    .00      1.83-012
 999.99
COLLFREQ
 500.00      2.00+002
 400.00      3.80+002
 370.00      3.90+002
 350.00      3.80+002
 330.00      3.50+002
 300.00      2.80+002
 250.00      1.05+002
 225.00      3.50+001
 220.00      3.00+001
 210.00      3.30+001
 200.00      4.50+001
 150.00      1.60+003
```

SAMPLE OUTPUT

```
  120.00      1.00+004
  104.00      3.00+004
     .00      1.82+011
  999.99
 STOP
```

```
199 INTEGRATION STEPS USED IN WAVFLD

MODAL EQN. VALUE =    -.85624-003  -.47601-003
NEW THETA =      89.89689024    -4.96334525
199 INTEGRATION STEPS USED IN WAVFLD

MODAL EQN. VALUE =    -.22750-004   .59081-004


ALTERNATIVE CHECK OF HOW WELL BOUNDARY CONDITIONS ARE SATISFIED


FIELD STRENGTHS AT HT =   50.0000
EX =    -.1228028+000  -.7505839-001     EY =     .7157429+001  -.3547941+002     EZ =     .1167723+001  -.4617074+001
HX =    -.9115202+000  -.1299195+000     HY =    -.1182348+001   .4671845+001     HZ =     .7178751+001  -.3561367+002

FIELD STRENGTHS AT HT =   50.0000
EX =    -.1227217+000  -.7493293-001     EY =     .7157429+001  -.3547941+002     EZ =     .1167723+001  -.4617074+001
HX =    -.9115218+000  -.1299023+000     HY =    -.1182348+001   .4671845+001     HZ =     .7178751+001  -.3561367+002
```

SAMPLE OUTPUT

```
ELECTRIC DIPOLE XMTR-ELECTRIC DIPOLE RCVR-EXC(I,J)

          EZ MAG      EZ ANG         EY MAG      EY ANG          EX MAG      EX ANG

 V     .101366-002    1.743       .758462-002    1.694       .101366-002    1.743

 HB    .765577-002    1.699       .573130-001    1.650       .765577-002    1.699

 HE    .101366-002   -1.398       .758462-002   -1.447       .101366-002   -1.398

ELECTRIC DIPOLE XMTR-MAGNETIC DIPOLE RECVR-MEXC(I,J)

          HZ MAG      HZ ANG         HY MAG      HY ANG          HX MAG      HX ANG

 V     .758462-002    1.694       .101366-002    1.743       .758462-002    1.694

 HB    .573130-001    1.650       .765577-002    1.699       .573130-001    1.650

 HE    .758462-002   -1.447       .101366-002   -1.398       .758462-002   -1.447


HEIGHT GAINS WITH HY NORMALIZED TO UNITY AT THE GROUND

FIELD STRENGTHS AT HT =      .0000
EX =    -.2546609+000  -.1437555+000    EY =    -.3997266+000  -.4401592+000    EZ =    -.1003753+001   .1560888-003
HX =    -.1904790+001  -.4587942+000    HY =     .1000000+001   .0000000        HZ =    -.4012954+000  -.4417487+000

FIELD STRENGTHS AT HT =     5.0000
EX =    -.2570230+000  -.1326362+000    EY =     .4536456+000  -.4012360+001    EZ =    -.7445745+000  -.4776753+000
HX =    -.1931847+001  -.4576281+000    HY =     .7428811+000   .4767521+000    HZ =     .4547218+000  -.4027489+001

FIELD STRENGTHS AT HT =    10.0000
EX =    -.2634507+000  -.1261878+000    EY =     .1311257+001  -.7664975+001    EZ =    -.5019799+000  -.9634059+000
HX =    -.1987635+001  -.4625051+000    HY =     .5015237+000   .9628957+000    HZ =     .1314982+001  -.7693944+001

FIELD STRENGTHS AT HT =    15.0000
EX =    -.2712007+000  -.1228573+000    EY =     .2179711+001  -.1143259+002    EZ =    -.2686855+000  -.1462072+001
HX =    -.2051695+001  -.4684154+000    HY =     .2687141+000   .1463508+001    HZ =     .2186107+001  -.1147584+002

FIELD STRENGTHS AT HT =    20.0000
EX =    -.2774484+000  -.1212240+000    EY =     .3056212+001  -.1531096+002    EZ =    -.4018585-001  -.1973506+001
HX =    -.2102748+001  -.4702764+000    HY =     .3997936-001   .1978480+001    HZ =     .3065291+001  -.1536890+002

FIELD STRENGTHS AT HT =    25.0000
EX =    -.2792537+000  -.1199322+000    EY =     .3928397+001  -.1925516+002    EZ =     .1854285+000  -.2492144+001
HX =    -.2118484+001  -.4629261+000    HY =    -.1865745+000   .2502288+001    HZ =     .3940134+001  -.1932804+002

FIELD STRENGTHS AT HT =    30.0000
EX =    -.2736040+000  -.1176619+000    EY =     .4774293+001  -.2317792+002    EZ =     .4075635+000  -.3006854+001
HX =    -.2075919+001  -.4412553+000    HY =    -.4103348+000   .3023766+001    HZ =     .4788593+001  -.2326565+002

FIELD STRENGTHS AT HT =    35.0000
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SAMPLE OUTPUT

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EX =   -.2575379+000  -.1131369+000    EY =    .5562651+001  -.2694920+002    EZ =    .6231941+000  -.3500902+001
HX =   -.1952385+001  -.4004821+000    HY =   -.6282358+000   .3526046+001    HZ =    .5579321+001  -.2705121+002

FIELD STRENGTHS AT HT =   40.0000
EX =   -.2283502+000  -.1051681+000    EY =    .6253912+001  -.3039816+002    EZ =    .8269856+000  -.3952245+001
HX =   -.1727129+001  -.3365579+000    HY =   -.8348618+000   .3986793+001    HZ =    .6272636+001  -.3051322+002

FIELD STRENGTHS AT HT =   45.0000
EX =   -.1838708+000  -.9272881-001    EY =    .6802044+001  -.3331868+002    EZ =    .1011525+001  -.4334262+001
HX =   -.1383487+001  -.2466874+000    HY =   -.1022664+001   .4378912+001    HZ =    .6822370+001  -.3344478+002

FIELD STRENGTHS AT HT =   50.0000
EX =   -.1228028+000  -.7505839-001    EY =    .7157429+001  -.3547941+002    EZ =    .1167723+001  -.4617074+001
HX =   -.9115202+000  -.1293195+000    HY =   -.1182348+001   .4671845+001    HZ =    .7178751+001  -.3561367+002

FIELD STRENGTHS AT HT =   55.0000
EX =   -.4501075-001  -.5165826-001    EY =    .7270833+001  -.3663894+002    EZ =    .1285186+001  -.4769374+001
HX =   -.3108883+000   .1226794-001    HY =   -.1303244+001   .4833399+001    HZ =    .7292400+001  -.3677758+002

FIELD STRENGTHS AT HT =   60.0000
EX =    .4779607-001  -.2292963-001    EY =    .7098594+001  -.3656639+002    EZ =    .1353793+001  -.4761566+001
HX =    .4063804+000   .1753233+000    HY =   -.1374880+001   .4832926+001    HZ =    .7119526+001  -.3670472+002

FIELD STRENGTHS AT HT =   65.0000
EX =    .1522890+000   .1041943-001    EY =    .6608826+001  -.3506660+002    EZ =    .1364214+001  -.4568887+001
HX =    .1213677+001   .3509884+000    HY =   -.1387470+001   .4644529+001    HZ =    .6628155+001  -.3519923+002

FIELD STRENGTHS AT HT =   70.0000
EX =    .2632274+000   .4655638-001    EY =    .5789450+001  -.3200861+002    EZ =    .1310407+001  -.4177960+001
HX =    .2068753+001   .5260520+000    HY =   -.1334253+001   .4253967+001    HZ =    .5806181+001  -.3212964+002

FIELD STRENGTHS AT HT =   75.0000
EX =    .3754899+000   .8133256-001    EY =    .4658211+001  -.2735475+002    EZ =    .1196444+001  -.3602136+001
HX =    .2913923+001   .6818943+000    HY =   -.1216904+001   .3676554+001    HZ =    .4671423+001  -.2745814+002

FIELD STRENGTHS AT HT =   80.0000
EX =    .5051596+000   .9284751-001    EY =    .3271048+001  -.2118964+002    EZ =    .1080754+001  -.2900346+001
HX =    .3674882+001   .7970680+000    HY =   -.1067631+001   .3004038+001    HZ =    .3280016+001  -.2126967+002

FIELD STRENGTHS AT HT =   85.0000
EX =    .1051623+001  -.1036718+000    EY =    .1711966+001  -.1377765+002    EZ =    .1231454+001  -.1554639+001
HX =    .4205467+001   .8699483+000    HY =   -.1115539+001   .2365336+001    HZ =    .1716240+001  -.1382963+002

FIELD STRENGTHS AT HT =   90.0000
EX =    .2500770+001   .1056639+001    EY =    .2309829+000  -.6001358+001    EZ =    .1572671-001  -.6073145+000
HX =    .3942202+001   .5876019+000    HY =   -.6951899+000   .6684161+000    HZ =    .2309130+000  -.6023916+001

FIELD STRENGTHS AT HT =   95.0000
EX =    .1666843+001   .3154096+000    EY =    .1575048+000  -.4586697+000    EZ =    .2936326-001  -.6765647-001
HX =    .1396176+001  -.5553139+000    HY =    .1215235+001  -.9191051+000    HZ =    .1580242+000  -.4604156+000

FIELD STRENGTHS AT HT =  100.0000
EX =   -.3897804+000   .2767017+000    EY =   -.2683607+000  -.4027665+000    EZ =   -.3490241-001  -.4326486-001
HX =    .7890973+000   .9587099+000    HY =   -.1032869+001   .7026058+000    HZ =   -.2694307+000  -.4042361+000

FIELD STRENGTHS AT HT =  105.0000
EX =   -.3314287+000  -.3769999+000    EY =    .3295788+000  -.3186358+000    EZ =    .3463264-001  -.4083927-001
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HX =    -.8571831+000   .7856211+000      HY =    -.8488067+000  -.9447479+000      HZ =     .3307659+000  -.3198830+000

FIELD STRENGTHS AT HT =  110.0000
EX =     .5219873+000  -.1919426+000      EY =     .1901460+000   .4501960+000      EZ =     .2792488-001   .5003454-001
HX =    -.3988290+000  -.9564429+000      HY =     .1085675+001  -.4360712+000      HZ =     .1909299+000   .4518558+000

FIELD STRENGTHS AT HT =  115.0000
EX =    -.3763528+000   .4847217+000      EY =    -.4146503+000  -.2901294+000      EZ =    -.5303552-001  -.2731933-001
HX =     .7659905+000   .5185262+000      HY =    -.6407850+000   .9066123+000      HZ =    -.4162517+000  -.2911535+000

FIELD STRENGTHS AT HT =  120.0000
EX =     .4176959+000  -.5450113+000      EY =     .4301032+000   .2810752+000      EZ =     .5638134-001   .2433900-001
HX =    -.6913764+000  -.4404731+000      HY =     .5985464+000  -.8668926+000      HZ =     .4317611+000   .2820629+000

FIELD STRENGTHS AT HT =  125.0000
EX =    -.6077898+000   .4047983+000      EY =    -.3204241+000  -.3974325+000      EZ =    -.4763372-001  -.3944930-001
HX =     .4803184+000   .5819914+000      HY =    -.8314939+000   .6161311+000      HZ =    -.3216886+000  -.3988740+000

FIELD STRENGTHS AT HT =  130.0000
EX =     .7745365+000  -.4705109-001      EY =     .8501502-001   .4921004+000      EZ =     .2464032-001   .5659289-001
HX =    -.1250385+000  -.6778183+000      HY =     .1017060+001  -.1124439+000      HZ =     .8541088-001   .4939339+000

FIELD STRENGTHS AT HT =  135.0000
EX =    -.6641921+000  -.4540883+000      EY =     .2231033+000  -.4338606+000      EZ =     .1252387-001  -.6013030-001
HX =    -.2899626+000   .5798535+000      HY =    -.8680126+000  -.5338321+000      HZ =     .2238729+000  -.4355237+000

FIELD STRENGTHS AT HT =  140.0000
EX =     .1840429+000   .8126564+000      EY =    -.4418743+000   .1682432+000      EZ =    -.4781950-001   .3783052-001
HX =     .5650004+000  -.2224047+000      HY =     .2706357+000   .9803989+000      HZ =    -.4435063+000   .1689435+000

FIELD STRENGTHS AT HT =  145.0000
EX =     .4734980+000  -.7083891+000      EY =     .4176169+000   .1944457+000      EZ =     .6033767-001   .6227270-002
HX =    -.5280528+000  -.2387344+000      HY =     .5262568+000  -.8700153+000      HZ =     .4192145+000   .1951102+000

FIELD STRENGTHS AT HT =  150.0000
EX =    -.8468589+000   .1221692+000      EY =    -.1350939+000  -.4373043+000      EZ =    -.3611925-001  -.4869217-001
HX =     .1753931+000   .5461651+000      HY =    -.9988627+000   .1901954+000      HZ =    -.1356692+000  -.4389244+000

FIELD STRENGTHS AT HT =  155.0000
EX =     .6545869+000   .5377594+000      EY =    -.2365730+000   .3977262+000      EZ =    -.1273424-001   .5946912-001
HX =     .2936002+000  -.5062666+000      HY =     .8141803+000   .6089797+000      HZ =    -.2373987+000   .3992557+000

FIELD STRENGTHS AT HT =  160.0000
EX =    -.7079927-001  -.8269487+000      EY =     .4606290+000  -.1059928+000      EZ =     .5283730-001  -.3078602-001
HX =    -.5921832+000   .1431606+000      HY =    -.1339852+000  -.1008126+001      HZ =     .4623411+000  -.1064624+000

FIELD STRENGTHS AT HT =  165.0000
EX =    -.4954733+000   .6390216+000      EY =    -.4168838+000  -.2445993+000      EZ =    -.5951377-001  -.1557687-001
HX =     .5545932+000   .3172421+000      HY =    -.5845856+000   .8335973+000      HZ =    -.4184864+000  -.2454521+000

FIELD STRENGTHS AT HT =  170.0000
EX =     .7665408+000  -.1793103+000      EY =     .1678178+000   .4626601+000      EZ =     .3485012-001   .5104889-001
HX =    -.2348198+000  -.6258253+000      HY =     .9809830+000  -.2806841+000      HZ =     .1685198+000   .4643702+000

FIELD STRENGTHS AT HT =  175.0000
EX =    -.7071289+000  -.2704195+000      EY =     .1293394+000  -.4846202+000      EZ =     .2391026-002  -.6201061-001
HX =    -.1755678+000   .6880864+000      HY =    -.9747462+000  -.3181816+000      HZ =     .1297491+000  -.4864591+000
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SAMPLE OUTPUT

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FIELD STRENGTHS AT HT =  180.0000
EX =      .4813082+000   .5455196+000     EY =    -.3478985+000   .3693935+000     EZ =    -.3282237-001   .5268795-001
HX =      .5091623+000  -.5526553+000     HY =     .7212058+000   .7393651+000     HZ =    -.3491465+000   .3708341+000

FIELD STRENGTHS AT HT =  185.0000
EX =     -.2578454+000  -.6433489+000     EY =     .4569129+000  -.2269430+000     EZ =     .4971528-001  -.3668238-001
HX =     -.7131548+000   .3640285+000     HY =    -.4365595+000  -.9497538+000     HZ =     .4585922+000  -.2278660+000

FIELD STRENGTHS AT HT =  190.0000
EX =      .1393562+000   .6453035+000     EY =    -.4887750+000   .1414023+000     EZ =    -.5541371-001   2589521-001
HX =      .8136408+000  -.2450945+000     HY =     .2742945+000   .1025529+001     HZ =    -.4905872+000   .1420093+000

FIELD STRENGTHS AT HT =  195.0000
EX =     -.1640093+000  -.5994212+000     EY =     .4762390+000  -.1601410+000     EZ =     .5373794-001  -.2668292-001
HX =     -.8602790+000   .2998283+000     HY =    -.3355426+000  -.1034190+001     HZ =     .4780013+000  -.1608164+000

FIELD STRENGTHS AT HT =  200.0000
EX =      .3320104+000   .4820073+000     EY =    -.3914858+000   .2979983+000     EZ =    -.4189300-001   .4079198-001
HX =      .7677427+000  -.5978275+000     HY =     .6746427+000   .8926001+000     HZ =    -.3929085+000   .2991778+000

FIELD STRENGTHS AT HT =  205.0000
EX =     -.5249506+000  -.1464840+000     EY =     .1105784+000  -.4625156+000     EZ =     .7153658-002  -.5583134-001
HX =     -.2328071+000   .1023311+001     HY =    -.1133409+001  -.2674828+000     HZ =     .1109212+000  -.4642686+000

FIELD STRENGTHS AT HT =  210.0000
EX =      .3248527+000  -.3905831+000     EY =     .3591419+000   .2814606+000     EZ =     .4537994-001   .2899749-001
HX =     -.8958775+000  -.6863565+000     HY =     .7444224+000  -.9643783+000     HZ =     .3605337+000   .2824608+000

FIELD STRENGTHS AT HT =  215.0000
EX =      .4051137+000   .2306825+000     EY =    -.2051983+000   .3780958+000     EZ =    -.2027326-001   .4641119-001
HX =      .5755821+000  -.1088922+001     HY =     .1145635+001   .6055305+000     HZ =    -.2059094+000   .3795467+000

FIELD STRENGTHS AT HT =  220.0000
EX =      .1823947+000   .3875730+000     EY =    -.3624276+000   .1764813+000     EZ =    -.4087045-001   .2396018-001
HX =      .1199446+001  -.6004509+000     HY =     .6229166+000   .1237119+001     HZ =    -.3637602+000   .1772002+000

FIELD STRENGTHS AT HT =  225.0000
EX =      .3127993+000   .2185256+000     EY =    -.2079095+000   .3010437+000     EZ =    -.2192427-001   .3690784-001
HX =      .8422145+000  -.1248611+001     HY =     .1270279+001   .8491308+000     HZ =    -.2086428+000   .3022059+000

FIELD STRENGTHS AT HT =  230.0000
EX =     -.9798832-001  -.3123709+000     EY =     .3042906+000  -.9459052-001     EZ =     .3492691-001  -.1320591-001
HX =     -.1670263+001   .5394126+000     HY =    -.5484570+000  -.1667711+001     HZ =     .3054178+000  -.9499300-001

FIELD STRENGTHS AT HT =  235.0000
EX =      .1368368+000  -.2457652+000     EY =     .2400773+000   .1363189+000     EZ =     .2893579-001   .1441130-001
HX =     -.1786987+001  -.9888567+000     HY =     .9710290+000  -.1779190+001     HZ =     .2409995+000   .1367930+000

FIELD STRENGTHS AT HT =  240.0000
EX =     -.9698682-001   .2215930+000     EY =    -.2172659+000  -.9838300-001     EZ =    -.2597318-001  -.1022286-001
HX =      .2173689+001   .9556404+000     HY =    -.9313993+000   .2153724+001     HZ =    -.2180966+000  -.9871830-001

FIELD STRENGTHS AT HT =  245.0000
EX =      .1875522+000  -.9015362-001     EY =     .8618467-001   .1867843+000     EZ =     .1110444-001   .2135228-001
HX =     -.1183546+001  -.2492635+001     HY =     .2450287+001  -.1181854+001     HZ =     .8653726-001   .1874718+000
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FIELD STRENGTHS AT HT =  250.0000
EX =   -.1173625+000   .1352338+000      EY =   -.1317511+000  -.1185853+000      EZ =   -.1602092-001  -.1316232-001
HX =    .2406096+001   .2118230+001      HY =   -.2071046+001   .2381869+001      HZ =   -.1322640+000  -.1190098+000

FIELD STRENGTHS AT HT =  255.0000
EX =    .1697581+000  -.4243803-001      EY =    .3892107-001   .1688217+000      EZ =    .5432867-002   .1952314-001
HX =   -.7717258+000  -.3186882+001      HY =    .3132704+001  -.7790381+000      HZ =    .3909348-001   .1694492+000

FIELD STRENGTHS AT HT =  260.0000
EX =   -.5969734-001   .1602341+000      EY =   -.1575393+000  -.6206597-001      EZ =   -.1873198-001  -.6431529-002
HX =    .3133784+001   .1194977+001      HY =   -.1157283+001   .3091958+001      HZ =   -.1581402+000  -.6227430-001

FIELD STRENGTHS AT HT =  265.0000
EX =   -.1282451+000   .1071082+000      EY =   -.1036527+000  -.1289956+000      EZ =   -.1278017-001  -.1453594-001
HX =    .2177974+001   .2650249+001      HY =   -.2595259+001   .2159687+001      HZ =   -.1040619+000  -.1294635+000

FIELD STRENGTHS AT HT =  270.0000
EX =    .5414179-001   .1540301+000      EY =   -.1535657+000   .5068886-001      EZ =   -.1768260-001   .6714371-002
HX =    .3319321+001  -.1136277+001      HY =    .1138360+001   .3259750+001      HZ =   -.1541341+000   .5090306-001

FIELD STRENGTHS AT HT =  275.0000
EX =   -.3505591-001  -.1556278+000      EY =    .1548096+000  -.3172310-001      EZ =    .1792637-001  -.4500536-002
HX =   -.3506893+001   .7589106+000      HY =   -.7680524+000  -.3446302+001      HZ =    .1553856+000  -.3186631-001

FIELD STRENGTHS AT HT =  280.0000
EX =    .1416041+000  -.6512740-001      EY =    .6174899-001   .1415280+000      EZ =    .7937231-002   .1622189-001
HX =   -.1504256+001  -.3346796+001      HY =    .3283956+001  -.1500402+001      HZ =    .6200282-001   .1420495+000

FIELD STRENGTHS AT HT =  285.0000
EX =    .7508848-001  -.1324722+000      EY =    .1297448+000   .7699287-001      EZ =    .1555100-001   .8337337-002
HX =   -.3247632+001  -.1879199+001      HY =    .1829197+001  -.3206645+001      HZ =    .1302437+000   .7726156-001

FIELD STRENGTHS AT HT =  290.0000
EX =   -.1214485+000   .8589745-001      EY =   -.8267545-001  -.1220262+000      EZ =   -.1027700-001  -.1384005-001
HX =    .2186752+001   .3152312+001      HY =   -.3087982+001   .2170443+001      HZ =   -.8300477-001  -.1224712+000

FIELD STRENGTHS AT HT =  295.0000
EX =   -.1022178+000  -.1032729+000      EY =    .1043738+000  -.9919185-001      EZ =    .1169606-001  -.1211523-001
HX =   -.2813383+001   .2733252+001      HY =   -.2705858+001  -.2751045+001      HZ =    .1047501+000  -.9958039-001

FIELD STRENGTHS AT HT =  300.0000
EX =   -.1414699+000   .1132259-001      EY =   -.8343060-002  -.1403986+000      EZ =   -.1678605-002  -.1636263-001
HX =    .2819087+000   .4000007+001      HY =   -.3932998+001   .3015685+000      HZ =   -.8396285-002  -.1409242+000

FIELD STRENGTHS AT HT =  305.0000
EX =    .1360729+000  -.2637344-001      EY =    .2334127-001   .1353702+000      EZ =    .3403092-002   .1570029-001
HX =   -.7409053+000  -.4031442+001      HY =    .3960917+001  -.7532244+000      HZ =    .2345000-001   .1358746+000

FIELD STRENGTHS AT HT =  310.0000
EX =    .1273986+000   .4572529-001      EY =   -.4794580-001   .1252952+000      EZ =   -.4978840-002   .1487802-001
HX =    .1454178+001  -.3929195+001      HY =    .3873466+001   .1406453+001      HZ =   -.4810617-001   .1257729+000

FIELD STRENGTHS AT HT =  315.0000
EX =   -.2091740-001  -.1305066+000      EY =    .1297639+000  -.1800603-001      EZ =    .1507238-001  -.2746856-002
HX =   -.4234640+001   .6351865+000      HY =   -.6504125+000  -.4161027+001      HZ =    .1302481+000  -.1809386-001

FIELD STRENGTHS AT HT =  320.0000
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SAMPLE OUTPUT

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EX =     .1249436+000  -.3230590-001     EY =     .2938889-001   .1244998+000     EZ =     .4048558-002   .1440134-001
HX =    -.1052180+001  -.4247647+001     HY =     .4171115+001  -.1060573+001     HZ =     .2951861-001   .1249624+000

FIELD STRENGTHS AT HT =  325.0000
EX =    -.8206323-002  -.1257274+000     EY =     .1247764+000  -.5470277-002     EZ =     .1455178-001  -.1253218-002
HX =    -.4464959+001   .2450244+000     HY =    -.2680579+000  -.4389567+001     HZ =     .1252438+000  -.5510282-002

FIELD STRENGTHS AT HT =  330.0000
EX =     .1185025+000   .3294663-001     EY =    -.3518034-001   .1167443+000     EZ =    -.3537702-002   .1381276-001
HX =     .1270032+001  -.4388887+001     HY =     .4323796+001   .1222337+001     HZ =    -.3529414-001   .1171879+000

FIELD STRENGTHS AT HT =  335.0000
EX =     .1053917+000   .6274437-001     EY =    -.6443416-001   .1031145+000     EZ =    -.7022613-002   .1236373-001
HX =     .2378609+001  -.3901447+001     HY =     .3851159+001   .2315479+001     HZ =    -.6465987-001   .1035116+000

FIELD STRENGTHS AT HT =  340.0000
EX =     .1006192+000   .6953792-001     EY =    -.7106646-001   .9823913-001     EZ =    -.7821513-002   .1182656-001
HX =     .2637416+001  -.3731693+001     HY =     .3685783+001   .2571017+001     HZ =    -.7131783-001   .9861890-001

FIELD STRENGTHS AT HT =  345.0000
EX =     .1085255+000   .5565010-001     EY =    -.5747215-001   .1063712+000     EZ =    -.6193393-002   .1270997-001
HX =     .2127833+001  -.4044115+001     HY =     .3989922+001   .2067990+001     HZ =    -.5767123-001   .1067794+000

FIELD STRENGTHS AT HT =  350.0000
EX =     .1203573+000   .1741548-001     EY =    -.1983163-001   .1189142+000     EZ =    -.1734158-002   .1399090-001
HX =     .7020383+000  -.4515455+001     HY =     .4444781+001   .6629915+000     HZ =    -.1988749-001   .1193636+000

FIELD STRENGTHS AT HT =  355.0000
EX =     .1194996+000  -.2254267-001     EY =     .1979032-001   .1189173+000     EZ =     .2895321-002   .1379701-001
HX =    -.7974512+000  -.4486133+001     HY =     .4406856+001  -.8114378+000     HZ =     .1988315-001   .1193605+000

FIELD STRENGTHS AT HT =  360.0000
EX =     .1155265+000  -.3795977-001     EY =     .3515599-001   .1153082+000     EZ =     .4673035-002   .1329996-001
HX =    -.1372733+001  -.4330880+001     HY =     .4250698+001  -.1376235+001     HZ =     .3530593-001   .1157355+000

FIELD STRENGTHS AT HT =  365.0000
EX =     .1178206+000  -.3007432-001     EY =     .2729278-001   .1174131+000     EZ =     .3764756-002   .1358442-001
HX =    -.1074188+001  -.4400809+001     HY =     .4321288+001  -.1083069+001     HZ =     .2741353-001   .1178494+000

FIELD STRENGTHS AT HT =  370.0000
EX =     .1215781+000   .1899670-002     EY =    -.4475526-002   .1204547+000     EZ =     .6805474-004   .1409563-001
HX =     .1179911+000  -.4515268+001     HY =     .4441090+001   .8863884-001     HZ =    -.4473520-002   .1209074+000

FIELD STRENGTHS AT HT =  375.0000
EX =     .1014215+000   .6740977-001     EY =    -.6896995-001   .9908127-001     EZ =    -.7572004-002   .1191498-001
HX =     .2528137+001  -.3718559+001     HY =     .3672235+001   .2463653+001     HZ =    -.6921332-001   .9946387-001

FIELD STRENGTHS AT HT =  380.0000
EX =     .1968299-003   .1219692+000     EY =    -.1208857+000  -.2401342-002     EZ =    -.1413585-001   .3130102-003
HX =     .4476318+001   .3961456-001     HY =    -.1179923-001   .4402350+001     HZ =    -.1213398+000  -.2391485-002

FIELD STRENGTHS AT HT =  385.0000
EX =    -.1201715+000   .2195589-001     EY =    -.1920418-001  -.1195663+000     EZ =    -.2831129-002  -.1387557-001
HX =     .7551482+000   .4392127+001     HY =    -.4314752+001   .7692803+000     HZ =    -.1929491-001  -.1200120+000

FIELD STRENGTHS AT HT =  390.0000
EX =     .5730440-002  -.1222201+000     EY =     .1210072+000   .8276269-002     EZ =     .1417894-001   .3723061-003
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HX =    -.4429529+001  -.2539850+000    HY =    .2229022+000  -.4357677+001    HZ =    .1214626+000   .8288441-002

FIELD STRENGTHS AT HT =  395.0000
EX =     .9539693-001   .7692805-001    EY =   -.7826604-001   .9291170-001    EZ =   -.8687671-002   .1124044-001
HX =     .2808420+001  -.3409451+001    HY =    .3370014+001   .2741215+001    HZ =   -.7854526-001   .9327260-001

FIELD STRENGTHS AT HT =  400.0000
EX =    -.1215227+000  -.1729859-001    EY =    .1972135-001  -.1200697+000    EZ =    .1713633-002  -.1412575-001
HX =    -.6649430+000   .4347168+001    HY =   -.4279214+001  -.6275572+000    HZ =    .1977662-001  -.1205234+000

FIELD STRENGTHS AT HT =  405.0000
EX =     .1150483+000   .4530701-001    EY =   -.4733480-001   .1130600+000    EZ =   -.4973750-002   .1344288-001
HX =     .1637088+001  -.4034349+001    HY =    .3977528+001   .1585524+001    HZ =   -.4749480-001   .1134916+000

FIELD STRENGTHS AT HT =  410.0000
EX =     .2067978-001  -.1228345+000    EY =    .1212966+000   .2309523-001    EZ =    .1428599-001   .2099155-002
HX =    -.4243302+001  -.7592724+000    HY =    .7209764+000  -.4177758+001    HZ =    .1217554+000   .2315293-001

FIELD STRENGTHS AT HT =  415.0000
EX =    -.6050604-001  -.1099430+000    EY =    .1102278+000  -.5764995-001    EZ =    .1259430-001  -.7279984-002
HX =    -.3760177+001   .2019632+001    HY =   -.2009085+001  -.3685815+001    HZ =    .1106325+000  -.5788351-001

FIELD STRENGTHS AT HT =  420.0000
EX =    -.1045706-001  -.1260039+000    EY =    .1250889+000  -.7720329-002    EZ =    .1457715-001  -.1520425-002
HX =    -.4215297+001   .3067812+000    HY =   -.3272914+000  -.4143874+001    HZ =    .1255571+000  -.7768826-002

FIELD STRENGTHS AT HT =  425.0000
EX =     .1257310+000  -.2052726-001    EY =    .1771301-001   .1250262+000    EZ =    .2688475-002   .1452034-001
HX =    -.6326709+000  -.4137207+001    HY =    .4065160+001  -.6473388+000    HZ =    .1779900-001   .1254926+000

FIELD STRENGTHS AT HT =  430.0000
EX =    -.9316709-001   .8830822-001    EY =   -.8556781-001  -.9416612-001    EZ =   -.1046450-001  -.1057823-001
HX =     .2821007+001   .3036633+001    HY =   -.2969504+001   .2792965+001    HZ =   -.8590363-001  -.9450615-001

FIELD STRENGTHS AT HT =  435.0000
EX =     .1227686+000  -.4075126-001    EY =    .3783062-001   .1225037+000    EZ =    .5028191-002   .1412559-001
HX =    -.1254293+001  -.3908539+001    HY =    .3836619+001  -.1257366+001    HZ =    .3799171-001   .1229576+000

FIELD STRENGTHS AT HT =  440.0000
EX =    -.5505286-001  -.1181605+000    EY =    .1182288+000  -.5210510-001    EZ =    .1355493-001  -.6675638-002
HX =    -.3701991+001   .1680422+001    HY =   -.1675259+001  -.3630950+001    HZ =    .1186644+000  -.5231909-001

FIELD STRENGTHS AT HT =  445.0000
EX =    -.1183996+000  -.5691972-001    EY =    .5884725-001  -.1161472+000    EZ =    .6297641-002  -.1386364-001
HX =    -.1780294+001   .3611839+001    HY =   -.3563337+001  -.1729155+001    HZ =    .5904997-001  -.1165922+000

FIELD STRENGTHS AT HT =  450.0000
EX =    -.9742170-001  -.8965842-001    EY =    .9084652-001  -.9468797-001    EZ =    .1014262-001  -.1151629-001
HX =    -.2729495+001   .2908319+001    HY =   -.2877179+001  -.2667090+001    HZ =    .9117267-001  -.9505750-001

FIELD STRENGTHS AT HT =  455.0000
EX =     .5617343-001  -.1210423+000    EY =    .1187838+000   .5814352-001    EZ =    .1416912-001   .6200608-002
HX =    -.3567438+001  -.1697816+001    HY =    .1648366+001  -.3519300+001    HZ =    .1192387+000   .5834318-001

FIELD STRENGTHS AT HT =  460.0000
EX =     .6409747-001   .1182418+000    EY =   -.1184693+000   .6109272-001    EZ =   -.1353674-001   .7730455-002
HX =     .3458445+001  -.1831924+001    HY =    .1822930+001   .3390751+001    HZ =   -.1189044+000   .6134048-001
```

SAMPLE OUTPUT

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FIELD STRENGTHS AT HT =  465.0000
EX =    -.6444014-001  -.1192723+000     EY =      .1194902+000  -.6141817-001     EZ =      .1365396-001  -.7774509-002
HX =    -.3428441+001   .1810195+001     HY =     -.1801411+001  -.3361440+001     HZ =      .1199290+000  -.6166731-001

FIELD STRENGTHS AT HT =  470.0000
EX =    -.5605294-001   .1246246+000     EY =     -.1223392+000  -.5806722-001     EZ =     -.1458559-001  -.6171219-002
HX =     .3487691+001   .1608618+001     HY =     -.1561214+001   .3440533+001     HZ =     -.1228074+000  -.5826604-001

FIELD STRENGTHS AT HT =  475.0000
EX =     .1079057+000   .8561790-001     EY =     -.8701052-001   .1051776+000     EZ =     -.9638285-002   .1272626-001
HX =     .2393027+001  -.2958358+001     HY =      .2924660+001   .2336086+001     HZ =     -.8732064-001   .1055859+000

FIELD STRENGTHS AT HT =  480.0000
EX =     .1350923+000   .3211100-001     EY =     -.3453658-001   .1331947+000     EZ =     -.3365316-002   .1573661-001
HX =     .9059823+000  -.3659298+001     HY =      .3605243+001   .8690463+000     HZ =     -.3464540-001   .1336999+000

FIELD STRENGTHS AT HT =  485.0000
EX =     .1100544+000   .8649992-001     EY =     -.8790681-001   .1072961+000     EZ =     -.9730696-002   .1297977-001
HX =     .2335103+001  -.2914992+001     HY =      .2881785+001   .2279480+001     HZ =     -.8821996-001   .1077125+000

FIELD STRENGTHS AT HT =  490.0000
EX =    -.5277033-001   .1308777+000     EY =     -.1286038+000  -.5489683-001     EZ =     -.1530362-001  -.5765287-002
HX =     .3419224+001   .1415287+001     HY =     -.1371589+001   .3372328+001     HZ =     -.1290950+000  -.5508277-001

FIELD STRENGTHS AT HT =  495.0000
EX =    -.8380777-001  -.1149598+000     EY =      .1155561+000  -.8073495-001     EZ =      .1309390-001  -.1001759-001
HX =    -.2982380+001   .2132894+001     HY =     -.2116426+001  -.2921132+001     HZ =      .1159772+000  -.8105597-001

FIELD STRENGTHS AT HT =  500.0000
EX =     .1045865+000   .9815013-001        =     -.9930609-001   .1016594+000     EZ =     -.1108856-001   .1238123-001
HX =     .2509929+001  -.2626607+001      Y =      .2599344+001   .2453407+001     HZ =     -.9966290-001   .1020564+000
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HEIGHT GAINS NORMALIZED FOR USE WITH WKB MODE SUMMING FORMULAS

FIELD STRENGTHS AT HT =      .0000
EX=     .7445885-001  -.1639186+000     EY=     .2697037-001  -.3783949-001     EZ=    -.5411622-001  -.6155869+000
HX=     .3383116-002  -.1530835+000     HY=     .5381852-001   .6132937+000     HZ=     .2706568-001  -.3798571-001

FIELD STRENGTHS AT HT =     5.0000
EX=     .6751233-001  -.1647689+000     EY=     .3139428+000  -.3203252-001     EZ=     .2528834+000  -.4823506+000
HX=     .2844433-002  -.1551304+000     HY=    -.2524083+000   .4812624+000     HZ=     .3151160+000  -.3220174-001

FIELD STRENGTHS AT HT =    10.0000
EX=     .6321165-001  -.1683639+000     EY=     .6071264+000  -.2723809-001     EZ=     .5638349+000  -.3597102+000
HX=     .2289814-002  -.1594717+000     HY=    -.5635466+000   .3594030+000     HZ=     .6094006+000  -.2743507-001

FIELD STRENGTHS AT HT =    15.0000
EX=     .6075196-001  -.1729377+000     EY=     .9092726+000  -.2352671-001     EZ=     .8822194+000  -.2434697+000
HX=     .1676648-002  -.1644618+000     HY=    -.8830985+000   .2435645+000     HZ=     .9126813+000  -.2375693-001

FIELD STRENGTHS AT HT =    20.0000
EX=     .5941406-001  -.1766815+000     EY=     .1220010+001  -.2104130-001     EZ=     .1208176+001  -.1308569+000
HX=     .9703836-003  -.1683914+000     HY=    -.1211238+001   .1309980+000     HZ=     .1224585+001  -.2131069-001

FIELD STRENGTHS AT HT =    25.0000
EX=     .5852467-001  -.1777191+000     EY=     .1535703+001  -.1997936-001     EZ=     .1538396+001  -.2040138-001
HX=     .1475938-003  -.1694709+000     HY=    -.1544678+001   .2024445-001     HZ=     .1541463+001  -.2029405-001

FIELD STRENGTHS AT HT =    30.0000
EX=     .5743637-001  -.1741320+000     EY=     .1849321+001  -.2056867-001     EZ=     .1866019+001   .8813169-001
HX=    -.7999739-003  -.1658603+000     HY=    -.1876540+001  -.8892109-001     HZ=     .1856258+001  -.2093452-001

FIELD STRENGTHS AT HT =    35.0000
EX=     .5552586-001  -.1640352+000     EY=     .2150416+001  -.2303468-001     EZ=     .2180620+001   .1937877+000
HX=    -.1860817-002  -.1557491+000     HY=    -.2196313+001  -.1955264+000     HZ=     .2158483+001  -.2345678-001

FIELD STRENGTHS AT HT =    40.0000
EX=     .5220943-001  -.1457058+000     EY=     .2425283+001  -.2755943-001     EZ=     .2468394+001   .2944811+000
HX=    -.2999208-002  -.1374851+000     HY=    -.2490006+001  -.2974521+000     HZ=     .2434380+001  -.2804142-001

FIELD STRENGTHS AT HT =    45.0000
EX=     .4697434-001  -.1177574+000     EY=     .2657418+001  -.3423292-001     EZ=     .2712614+001   .3870985+000
HX=    -.4151725-002  -.1097495+000     HY=    -.2740597+001  -.3915266+000     HZ=     .2667385+001  -.3477618-001

FIELD STRENGTHS AT HT =    50.0000
EX=     .3942377-001  -.7935373-001     EY=     .2828327+001  -.4299968-001     EZ=     .2894467+001   .4676728+000
HX=    -.5225834-002  -.7176728-001     HY=    -.2928845+001  -.4736947+000     HZ=     .2838935+001  -.4360252-001

FIELD STRENGTHS AT HT =    55.0000
EX=     .2925927-001  -.3038498-001     EY=     .2918760+001  -.5360808-001     EZ=     .2994194+001   .5315156+000
HX=    -.6103015-002  -.2353716-001     HY=    -.3034432+001  -.5391452+000     HZ=     .2929705+001  -.5426485-001

FIELD STRENGTHS AT HT =    60.0000
EX=     .1663491-001   .2807899-001     EY=     .2910357+001  -.6555540-001     EZ=     .2993097+001   .5740122+000
HX=    -.6635577-002   .3394671-001     HY=    -.3037997+001  -.5831046+000     HZ=     .2921269+001  -.6625569-001
```

SAMPLE OUTPUT

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FIELD STRENGTHS AT HT =   65.0000
EX=     .1805796-002   .9395864-001      EY=     .2787687+001  -.7803387-001      EZ=     .2875490+001   .5907729+000
HX=    -.6635047-002   .9851510-001      HY=    -.2923132+001  -.6009647+000      HZ=     .2798136+001  -.7876184-001

FIELD STRENGTHS AT HT =   70.0000
EX=    -.1438623-001   .1639413+000      EY=     .2540547+001  -.8978970-001      EZ=     .2632841+001   .5788129+000
HX=    -.5794604-002   .1667222+000      HY=    -.2680738+001  -.5893468+000      HZ=     .2550068+001  -.9052321-001

FIELD STRENGTHS AT HT =   75.0000
EX=    -.2967243-001   .2346628+000      EY=     .2166357+001  -.9884159-001      EZ=     .2273558+001   .5399100+000
HX=    -.3650947-002   .2338534+000      HY=    -.2320299+001  -.5484526+000      HZ=     .2174471+001  -.9955067-001

FIELD STRENGTHS AT HT =   80.0000
EX=    -.2975585-001   .3148081+000      EY=     .1672506+001  -.1023240+000      EZ=     .1836928+001   .5067273+000
HX=     .1989978-003   .2938780+000      HY=    -.1899816+001  -.4930983+000      HZ=     .1678766+001  -.1029690+000

FIELD STRENGTHS AT HT =   85.0000
EX=     .1201780+000   .6393743+000      EY=     .1080581+001  -.9821510-001      EZ=     .1019725+001   .6715747+000
HX=     .3450460-002   .3356073+000      HY=    -.1510682+001  -.5568541+000      HZ=     .1084621+001  -.9875235-001

FIELD STRENGTHS AT HT =   90.0000
EX=    -.5134425+000   .1590573+001      EY=     .4621328+000  -.8208827-001      EZ=     .3733086+000  -.2303968-001
HX=     .2063709-001   .3108112+000      HY=    -.4473495+000  -.3903824+000      HZ=     .4638543+000  -.8246847-001

FIELD STRENGTHS AT HT =   95.0000
EX=    -.1037317+000   .1039239+001      EY=     .3764369-001   .4405945-002      EZ=     .4307358-001   .1436713-001
HX=     .6560750-001   .9739121-001      HY=     .6290835+000   .6958310+000      HZ=     .3778565-001   .4416604-002

FIELD STRENGTHS AT HT =  100.0000
EX=    -.1906768+000  -.2241582+000      EY=     .2629784-001  -.2718635-001      EZ=     .2465567-001  -.2373388-001
HX=    -.6009920-001   .7619082-001      HY=    -.4864911+000  -.5956385+000      HZ=     .2639229-001  -.2729248-001

FIELD STRENGTHS AT HT =  105.0000
EX=     .2133747+000  -.2235527+000      EY=     .2980942-001   .1987340-001      EZ=     .2691035-001   .1904207-001
HX=    -.7423825-001  -.5240387-001      HY=     .5337264+000  -.5714127+000      HZ=     .2992439-001   .1994333-001

FIELD STRENGTHS AT HT =  110.0000
EX=     .1458098+000   .3098015+000      EY=    -.3121953-001   .2200163-001      EZ=    -.2918299-001   .1981894-001
HX=     .6641135-001  -.4635027-001      HY=     .3258692+000   .6423691+000      HZ=    -.3133325-001   .2208908-001

FIELD STRENGTHS AT HT =  115.0000
EX=    -.3175315+000  -.2047278+000      EY=     .1526533-001  -.3648603-001      EZ=     .1390048-001  -.3399664-001
HX=    -.2686850-001   .6711154-001      HY=    -.5905057+000  -.3441969+000      HZ=     .1531693-001  -.3662534-001

FIELD STRENGTHS AT HT =  120.0000
EX=     .3567317+000   .2268386+000      EY=    -.1431712-001   .3751563-001      EZ=    -.1189260-001   .3588821-001
HX=     .2214786-001  -.6011658-001      HY=     .5638726+000   .3204298+000      HZ=    -.1436500-001   .3765866-001

FIELD STRENGTHS AT HT =  125.0000
EX=    -.2809706+000  -.3509680+000      EY=     .2502535-001  -.3107354-001      EZ=     .2163043-001  -.3133656-001
HX=    -.3646217-001   .4635078-001      HY=    -.4226191+000  -.4767907+000      HZ=     .2511441-001  -.3119406-001

FIELD STRENGTHS AT HT =  130.0000
EX=     .7054055-001   .4724861+000      EY=    -.3616657-001   .1466964-001      EZ=    -.3338196-001   .1815750-001
HX=     .4968385-001  -.2081220-001      HY=     .1236978+000   .6177050+000      HZ=    -.3630001-001   .1473034-001
```

SAMPLE OUTPUT

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FIELD STRENGTHS AT HT =  135.0000
EX=     .2427436+000  -.4317832+000     EY=     .3683923-001   .9827651-002     EZ=     .3755155-001   .4444688-002
HX=    -.4909902-001  -.1250733-001     HY=     .2806807+000  -.5610767+000     HZ=     .3697901-001   .9858782-002

FIELD STRENGTHS AT HT =  140.0000
EX=    -.4884921+000   .1566083+000     EY=    -.2019074-001  -.3094801-001     EZ=    -.2577480-001  -.2729141-001
HX=     .2637283-001   .3945052-001     HY=    -.5867073+000   .2187428+000     HZ=    -.2027134-001  -.3106100-001

FIELD STRENGTHS AT HT =  145.0000
EX=     .4599336+000   .2522689+000     EY=    -.7909139-002   .3512256-001     EZ=    -.5718610-003   .3733986-001
HX=     .9456087-002  -.4429197-001     HY=     .5618973+000   .2759270+000     HZ=    -.7933338-002   .3525560-001

FIELD STRENGTHS AT HT =  150.0000
EX=    -.1205023+000  -.5127983+000     EY=     .3114988-001  -.1758335-001     EZ=     .2791871-001  -.2477225-001
HX=    -.3879337-001   .2246979-001     HY=    -.1704029+000  -.6023601+000     HZ=     .3126403-001  -.1765420-001

FIELD STRENGTHS AT HT =  155.0000
EX=    -.2945755+000   .4303954+000     EY=    -.3430365-001  -.1145672-001     EZ=    -.3715737-001  -.4609286-002
HX=     .4354000-001   .1400795-001     HY=    -.3296654+000   .5321060+000     HZ=    -.3443417-001  -.1149436-001

FIELD STRENGTHS AT HT =  160.0000
EX=     .5033521+000  -.8792590-001     EY=     .1574863-001   .3341465-001     EZ=     .2172450-001   .3074793-001
HX=    -.2077306-001  -.4284318-001     HY=     .6110667+000  -.1364281+000     HZ=     .1581295-001   .3353759-001

FIELD STRENGTHS AT HT =  165.0000
EX=    -.4185735+000  -.2694795+000     EY=     .1175130-001  -.3589999-001     EZ=     .6350256-002  -.3733774-001
HX=    -.1501030-001   .4762333-001     HY=    -.5427015+000  -.3136597+000     HZ=     .1178980-001  -.3603655-001

FIELD STRENGTHS AT HT =  170.0000
EX=     .1512240+000   .4604644+000     EY=    -.3254239-001   .2050366-001     EZ=    -.2943238-001   .2412074-001
HX=     .4388911-001  -.2833166-001     HY=     .2249368+000   .5865247+000     HZ=    -.3266131-001   .2058568-001

FIELD STRENGTHS AT HT =  175.0000
EX=     .1277899+000  -.4482313+000     EY=     .3915737-001   .1823863-002     EZ=     .3815940-001  -.1870919-002
HX=    -.5546329-001  -.1973011-002     HY=     .1426793+000  -.6149298+000     HZ=     .3930460-001   .1824595-002

FIELD STRENGTHS AT HT =  180.0000
EX=    -.3086604+000   .3245423+000     EY=    -.3398997-001  -.2042893-001     EZ=    -.3407964-001  -.1729416-001
HX=     .5066457-001   .2969852-001     HY=    -.4146337+000   .4821025+000     HZ=    -.3412072-001  -.2050029-001

FIELD STRENGTHS AT HT =  185.0000
EX=     .3806850+000  -.1927591+000     EY=     .2492326-001   .3112099-001     EZ=     .2517268-001   .2851588-001
HX=    -.3964990-001  -.4841092-001     HY=     .5589830+000  -.3188535+000     HZ=     .2502165-001   .3123389-001

FIELD STRENGTHS AT HT =  190.0000
EX=    -.3882606+000   .1201955+000     EY=    -.1892040-001  -.3497561-001     EZ=    -.1886365-001  -.3259124-001
HX=     .3223731-001   .5806092-001     HY=    -.6141886+000   .2234156+000     HZ=    -.1899687-001  -.3510392-001

FIELD STRENGTHS AT HT =  195.0000
EX=     .3587945+000  -.1328458+000     EY=     .2014307-001   .3370691-001     EZ=     .1925656-001   .3152110-001
HX=    -.3719207-001  -.6071292-001     HY=     .6162037+000  -.2614447+000     HZ=     .2022392-001   .3383026-001

FIELD STRENGTHS AT HT =  200.0000
EX=    -.2777437+000   .2295608+000     EY=    -.2926218-001  -.2494389-001     EZ=    -.2727209-001  -.2349735-001
HX=     .5841110-001   .4869439-001     HY=    -.5111177+000   .4617925+000     HZ=    -.2937589-001  -.2503293-001

FIELD STRENGTHS AT HT =  205.0000
```

SAMPLE OUTPUT

```
EX=   .6158562-001  -.3298325+000    EY=   .3715759-001   .7584995-003    EZ=   .3462601-001   .1382533-002
HX=  -.8201394-001  -.7735078-003    HY=   .1030471+000  -.7095081+000    HZ=   .3729716-001   .7555462-003

FIELD STRENGTHS AT HT =  210.0000
EX=   .2570252+000   .1782095+000    EY=  -.1552574-001   .3210307-001    EZ=  -.1534170-001   .2939183-001
HX=   .3752649-001  -.7981929-001    HY=   .6315108+000   .4046482+000    HZ=  -.1557900-001   .3222597-001

FIELD STRENGTHS AT HT =  215.0000
EX=  -.1196735+000   .2608687+000    EY=  -.3228320-001  -.9387004-002    EZ=  -.2955477-001  -.9935679-002
HX=   .9272034-001   .2585929-001    HY=  -.3097117+000   .7351997+000    HZ=  -.3240582-001  -.9417193-002

FIELD STRENGTHS AT HT =  220.0000
EX=  -.2278799+000   .1327201+000    EY=  -.1949964-001  -.2474415-001    EZ=  -.1689421-001  -.2377609-001
HX=   .6578525-001   .8161789-001    HY=  -.7251930+000   .4486107+000    HZ=  -.1957668-001  -.2483397-001

FIELD STRENGTHS AT HT =  225.0000
EX=  -.1171860+000   .2035985+000    EY=  -.2644416-001  -.1087445-001    EZ=  -.2381528-001  -.1145969-001
HX=   .1093458+000   .4356707-001    HY=  -.4524020+000   .8247531+000    HZ=  -.2654510-001  -.1091114-001

FIELD STRENGTHS AT HT =  230.0000
EX=   .1863015+000  -.7690696-001    EY=   .1227995-001   .2166533-001    EZ=   .9978815-002   .2070973-001
HX=  -.6894783-001  -.1185862+000    HY=   .9932797+000  -.4261190+000    HZ=   .1232942-001   .2174472-001

FIELD STRENGTHS AT HT =  235.0000
EX=   .1580906+000   .7069440-001    EY=  -.6420534-002   .2059880-001    EZ=  -.7281075-002   .1852173-001
HX=   .4581898-001  -.1528957+000    HY=   .1143426+001   .4997726+000    HZ=  -.6441414-002   .2067711-001

FIELD STRENGTHS AT HT =  240.0000
EX=  -.1411213+000  -.4755560-001    EY=   .3902623-002  -.1822641-001    EZ=   .4871776-002  -.1647937-001
HX=  -.3685641-001   .1818743+000    HY=  -.1370992+001  -.4553111+000    HZ=   .3914424-002  -.1829542-001

FIELD STRENGTHS AT HT =  245.0000
EX=   .6538443-001   .1101727+000    EY=  -.1283164-001   .9685382-002    EZ=  -.1249760-001   .7959430-002
HX=   .1706828+000  -.1318029+000    HY=   .8566944+000   .1439140+001    HZ=  -.1287828-001   .9723733-002

FIELD STRENGTHS AT HT =  250.0000
EX=  -.8925430-001  -.6469959-001    EY=   .6866415-002  -.1203177-001    EZ=   .7210145-002  -.1053391-001
HX=  -.1217757+000   .2189414+000    HY=  -.1572246+001  -.1141971+001    HZ=   .6890305-002  -.1207800-001

FIELD STRENGTHS AT HT =  255.0000
EX=   .3516311-001   .1018276+000    EY=  -.1224532-001   .5777599-002    EZ=  -.1168103-001   .4382650-002
HX=   .2305425+000  -.1118908+000    HY=   .6463766+000   .1879341+001    HZ=  -.1229037-001   .5801192-002

FIELD STRENGTHS AT HT =  260.0000
EX=  -.1014834+000  -.2798843-001    EY=   .2121772-002  -.1306189-001    EZ=   .2936289-002  -.1183434-001
HX=  -.3917903-001   .2591693+000    HY=  -.1958562+001  -.5433499+000    HZ=   .2127696-002  -.1311124-001

FIELD STRENGTHS AT HT =  265.0000
EX=  -.7259076-001  -.7288750-001    EY=   .8128315-002  -.1005903-001    EZ=   .8226988-002  -.8620301-002
HX=  -.1661942+000   .2103616+000    HY=  -.1464196+001  -.1475425+001    HZ=   .8157249-002  -.1009805-001

FIELD STRENGTHS AT HT =  270.0000
EX=  -.9155189-001   .4149449-001    EY=  -.6422732-002  -.1088474-001    EZ=  -.5069533-002  -.1048327-001
HX=   .1419306+000   .2345983+000    HY=  -.1937919+001   .8735838+000    HZ=  -.6448534-002  -.1092459-001

FIELD STRENGTHS AT HT =  275.0000
EX=   .9355891-001  -.2987523-001    EY=   .4995080-002   .1129490-001    EZ=   .3724921-002   .1075191-001
```

```
HX=   -.1162299+000  -.2551931+000   HY=   .2072260+001  -.6565166+000   HZ=   .5015589-002   .1133651-001

FIELD STRENGTHS AT HT =  280.0000
EX=    .4756315-001   .8333984-001   EY=  -.9781690-002   .7067304-002   EZ=  -.9521614-002   .5740892-002
HX=    .2305815+000  -.1704879+000   HY=   .1096925+001   .1933280+001   HZ=  -.9817296-002   .7095353-002

FIELD STRENGTHS AT HT =  285.0000
EX=    .8528553-001   .3892183-001   EY=  -.3723541-002   .1118740-001   EZ=  -.4276305-002   .9986032-002
HX=    .8953788-001  -.2792333+000   HY=   .2065060+001   .9492573+000   HZ=  -.3735768-002   .1122997-001

FIELD STRENGTHS AT HT =  290.0000
EX=   -.5921654-001  -.6986073-001   EY=   .7944690-002  -.8341286-002   EZ=   .7934925-002  -.7047672-002
HX=   -.2043884+000   .2193750+000   HY=  -.1497309+001  -.1777030+001   HZ=   .7973203-002  -.8373829-002

FIELD STRENGTHS AT HT =  295.0000
EX=    .5783543-001  -.6824754-001   EY=   .9309225-002   .6322204-002   EZ=   .8059660-002   .6521093-002
HX=   -.2554764+000  -.1694246+000   HY=   .1541573+001  -.1807543+001   HZ=   .9345147-002   .6344477-002

FIELD STRENGTHS AT HT =  300.0000
EX=   -.1455784-001  -.8615321-001   EY=   .1058291-001  -.2970186-002   EZ=   .9944759-002  -.1910091-002
HX=   -.3007764+000   .8799793-001   HY=  -.3966182+000  -.2395853+001   HZ=   .1062217-001  -.2982985-002

FIELD STRENGTHS AT HT =  305.0000
EX=    .2349791-001   .8203325-001   EY=  -.9949692-002   .4031968-002   EZ=  -.9445741-002   .2932062-002
HX=    .2955496+000  -.1235716+000   HY=   .6751185+000   .2388668+001   HZ=  -.9986402-002   .4048652-002

FIELD STRENGTHS AT HT =  310.0000
EX=   -.2118663-001   .8059360-001   EY=  -.1036492-001  -.1579299-002   EZ=  -.9392550-002  -.2252778-002
HX=    .3242182+000   .4575527-001   HY=  -.6541045+000   .2451266+001   HZ=  -.1040406-001  -.1583608-002

FIELD STRENGTHS AT HT =  315.0000
EX=    .7891314-001  -.1985218-001   EY=   .3531379-002   .9610224-002   EZ=   .2495803-002   .9095961-002
HX=   -.1188750+000  -.3128236+000   HY=   .2516927+001  -.6228342+000   HZ=   .3546132-002   .9645738-002

FIELD STRENGTHS AT HT =  320.0000
EX=    .2653729-001   .7488848-001   EY=  -.9019071-002   .4313155-002   EZ=  -.8614361-002   .3258014-002
HX=    .3068875+000  -.1509349+000   HY=   .8749262+000   .2501040+001   HZ=  -.9052245-002   .4330749-002

FIELD STRENGTHS AT HT =  325.0000
EX=    .7666616-001  -.1179935-001   EY=   .2491205-002   .9437662-002   EZ=   .1551746-002   .8857071-002
HX=   -.9290758-001  -.3368954+000   HY=   .2677667+001  -.4006382+000   HZ=   .2502027-002   .9472691-002

FIELD STRENGTHS AT HT =  330.0000
EX=   -.1382833-001   .7444995-001   EY=  -.9499797-002  -.7465580-003   EZ=  -.8661671-002  -.1426268-002
HX=    .3562626+000   .2405397-001   HY=  -.5169515+000   .2717541+001   HZ=  -.9535565-002  -.7478769-003

FIELD STRENGTHS AT HT =  335.0000
EX=   -.3280870-001   .6801290-001   EY=  -.8945085-002  -.3207021-002   EZ=  -.7960544-002  -.3641526-002
HX=    .3374609+000   .1168106+000   HY=  -.1212805+001   .2486507+001   HZ=  -.8979155-002  -.3217660-002

FIELD STRENGTHS AT HT =  340.0000
EX=   -.3723199-001   .6545154-001   EY=  -.8682987-002  -.3794514-002   EZ=  -.7674096-002  -.4160397-002
HX=    .3287983+000   .1393953+000   HY=  -.1378425+001   .2398836+001   HZ=  -.8716165-002  -.3807399-002

FIELD STRENGTHS AT HT =  345.0000
EX=   -.2828917-001   .6955299-001   EY=  -.9078089-002  -.2621248-002   EZ=  -.8128265-002  -.3114337-002
HX=    .3441885+000   .9528934-001   HY=  -.1053553+001   .2558290+001   HZ=  -.9112567-002  -.2629669-002
```

SAMPLE OUTPUT

```
FIELD STRENGTHS AT HT =  350.0000
EX=     -.4203357-002   .7475162-001      EY=    -.9410450-002   .4616074-003      EZ=    -.8673860-002  -.3105785-003
HX=      .3564893+000  -.2142414-001      HY=    -.1673969+000   .2761637+001      HZ=    -.9445693-002   .4648086-003

FIELD STRENGTHS AT HT =  355.0000
EX=      .2025657-001   .7207513-001      EY=    -.8752270-002   .3487393-002      EZ=    -.8305800-002   .2518217-002
HX=      .3293324+000  -.1354456+000      HY=     .7348202+000   .2659027+001      HZ=    -.8784571-002   .3501847-002

FIELD STRENGTHS AT HT =  360.0000
EX=      .2949796-001   .6880876-001      EY=    -.8221323-002   .4600821-002      EZ=    -.7905287-002   .3581727-002
HX=      .3079168+000  -.1767972+000      HY=     .1072803+001   .2532859+001      HZ=    -.8251458-002   .4619370-002

FIELD STRENGTHS AT HT =  365.0000
EX=      .2478532-001   .7064010-001      EY=    -.8512725-002   .4035323-002      EZ=    -.8128627-002   .3039995-002
HX=      .3182181+000  -.1551607+000      HY=     .8968048+000   .2591929+001      HZ=    -.8544041-002   .4051795-002

FIELD STRENGTHS AT HT =  370.0000
EX=      .5378100-002   .7466534-001      EY=    -.9272905-002   .1659876-002      EZ=    -.8641100-002   .8003436-003
HX=      .3467697+000  -.6602186-001      HY=     .1846513+000   .2728463+001      HZ=    -.9307446-002   .1667553-002

FIELD STRENGTHS AT HT =  375.0000
EX=     -.3588363-001   .6582904-001      EY=    -.8712457-002  -.3620420-002      EZ=    -.7714894-002  -.4002616-002
HX=      .3259794+000   .1312685+000      HY=    -.1313308+001   .2384749+001      HZ=    -.8745719-002  -.3632647-002

FIELD STRENGTHS AT HT =  380.0000
EX=     -.7479235-001   .6684917-002      EY=    -.1825435-002  -.9271358-002      EZ=    -.9527378-003  -.8652583-002
HX=      .7135984-001   .3424928+000      HY=    -.2700568+001   .2296916+000      HZ=    -.1833733-002  -.9305867-002

FIELD STRENGTHS AT HT =  385.0000
EX=     -.1993286-001  -.7251880-001      EY=     .8811567-002  -.3453417-002      EZ=     .8357430-002  -.2483076-002
HX=     -.3228566+000   .1306530+000      HY=    -.7040084+000  -.2604809+001      HZ=     .8844096-002  -.3467752-002

FIELD STRENGTHS AT HT =  390.0000
EX=      .7526519-001  -.3063261-002      EY=     .1378813-002   .9378258-002      EZ=     .5347566-003   .8715891-002
HX=     -.5421191-001  -.3424821+000      HY=     .2684532+001  -.9781920-001      HZ=     .1385451-002   .9413237-002

FIELD STRENGTHS AT HT =  395.0000
EX=     -.4204536-001   .6264649-001      EY=    -.8395795-002  -.4432839-002      EZ=    -.7361251-002  -.4723150-002
HX=      .3070319+000   .1578089+000      HY=    -.1499800+001   .2214336+001      HZ=    -.8427995-002  -.4448164-002

FIELD STRENGTHS AT HT =  400.0000
EX=      .4068940-002  -.7546010-001      EY=     .9496855-002  -.4892300-003      EZ=     .8755460-002   .2907329-003
HX=     -.3430216+000   .2146042-001      HY=     .1545759+000  -.2658189+001      HZ=     .9532418-002  -.4925483-003

FIELD STRENGTHS AT HT =  405.0000
EX=     -.2159477-001   .7299675-001      EY=    -.9420421-002  -.1735959-002      EZ=    -.8512114-002  -.2326893-002
HX=      .3352878+000   .5797578-001      HY=    -.7583271+000   .2524723+001      HZ=    -.9456045-002  -.1741003-002

FIELD STRENGTHS AT HT =  410.0000
EX=      .7644657-001   .6072010-002      EY=     .2527354-003   .9646448-002      EZ=    -.5185476-003   .8874484-002
HX=     -.1253096-001  -.3366574+000      HY=     .2600994+001   .2173296+000      HZ=     .2551896-003   .9682610-002

FIELD STRENGTHS AT HT =  415.0000
EX=      .6417102-001  -.4302494-001      EY=     .6234151-002   .7459563-002      EZ=     .5142575-002   .7332205-002
HX=     -.2167140+000  -.2535852+000      HY=     .2152361+001  -.1430524+001      HZ=     .6258711-002   .7486585-002
```

SAMPLE OUTPUT

```
FIELD STRENGTHS AT HT =  420.0000
EX=     .7671460-001  -.1319459-001     EY=     .2668223-002   .9424136-002     EZ=     .1716987-002   .8856247-002
HX=    -.9347490-001  -.3168037+000     HY=     .2523797+001  -.4237429+000     HZ=     .2679707-002   .9459087-002

FIELD STRENGTHS AT HT =  425.0000
EX=     .1935590-001   .7600526-001     EY=    -.9253293-002   .3430273-002     EZ=    -.8760543-002   .2430288-002
HX=     .3054249+000  -.1170638+000     HY=     .6157897+000   .2458298+001     HZ=    -.9287484-002   .3444591-002

FIELD STRENGTHS AT HT =  430.0000
EX=    -.5917299-001  -.5238617-001     EY=     .5769087-002  -.8099197-002     EZ=     .5924376-002  -.6987116-002
HX=    -.1850149+000   .2658877+000     HY=    -.1872722+001  -.1670865+001     HZ=     .5789473-002  -.8130493-002

FIELD STRENGTHS AT HT =  435.0000
EX=     .3159972-001   .7310003-001     EY=    -.8726364-002   .4924640-002     EZ=    -.8392528-002   .3843977-002
HX=     .2776328+000  -.1607342+000     HY=     .9776156+000   .2285305+001     HZ=    -.8758344-002   .4944484-002

FIELD STRENGTHS AT HT =  440.0000
EX=     .6950425-001  -.4012280-001     EY=     .5943674-002   .8162702-002     EZ=     .4823633-002   .7953881-002
HX=    -.1898433+000  -.2547786+000     HY=     .2136679+001  -.1222838+001     HZ=     .5967253-002   .8192407-002

FIELD STRENGTHS AT HT =  445.0000
EX=     .2853641-001  -.7567706-001     EY=     .9847484-002   .2563807-002     EZ=     .8841415-002   .3116183-002
HX=    -.3054024+000  -.7593276-001     HY=     .8687060+000  -.2278433+001     HZ=     .9884840-002   .2571891-002

FIELD STRENGTHS AT HT =  450.0000
EX=     .4974385-001  -.6457340-001     EY=     .8740496-002   .5364032-002     EZ=     .7608728-002   .5600617-002
HX=    -.2674513+000  -.1601093+000     HY=     .1480864+001  -.1908095+001     HZ=     .8774135-002   .5382798-002

FIELD STRENGTHS AT HT =  455.0000
EX=     .7725765-001   .2793649-001     EY=    -.2466252-002   .1003714-001     EZ=    -.3040233-002   .9023539-002
HX=     .7037215-001  -.3006412+000     HY=     .2247077+001   .8215287+000     HZ=    -.2473940-002   .1007519-001

FIELD STRENGTHS AT HT =  460.0000
EX=    -.6906730-001   .4567417-001     EY=    -.6634011-002  -.8031718-002     EZ=    -.5469566-002  -.7885953-002
HX=     .1973657+000   .2336627+000     HY=    -.1981419+001   .1300477+001     HZ=    -.6660161-002  -.8060824-002

FIELD STRENGTHS AT HT =  465.0000
EX=     .6968090-001  -.4593979-001     EY=     .6675828-002   .8104266-002     EZ=     .5502893-002   .7955473-002
HX=    -.1952077+000  -.2317324+000     HY=     .1964601+001  -.1285702+001     HZ=     .6702146-002   .8133638-002

FIELD STRENGTHS AT HT =  470.0000
EX=    -.7944816-001  -.2766980-001     EY=     .2401343-002  -.1030738-001     EZ=     .2999794-002  -.9277379-002
HX=    -.6488572-001   .2930690+000     HY=    -.2194079+001  -.7723183+000     HZ=     .2408746-002  -.1034643-001

FIELD STRENGTHS AT HT =  475.0000
EX=    -.4670159-001   .7078572-001     EY=    -.9477796-002  -.4896783-002     EZ=    -.8323650-002  -.5226191-002
HX=     .2656813+000   .1335834+000     HY=    -.1275306+001   .1919400+001     HZ=    -.9514129-002  -.4913681-002

FIELD STRENGTHS AT HT =  480.0000
EX=    -.1242301-001   .8457940-001     EY=    -.1074534-001  -.4240328-003     EZ=    -.9832280-002  -.1217006-002
HX=     .2944979+000   .8377210-002     HY=    -.3389518+000   .2257844+001     HZ=    -.1078573-001  -.4239469-003

FIELD STRENGTHS AT HT =  485.0000
EX=    -.4712689-001   .7215098-001     EY=    -.9654465-002  -.4930025-002     EZ=    -.8484105-002  -.5269222-002
HX=     .2614072+000   .1298807+000     HY=    -.1242897+001   .1890059+001     HZ=    -.9691466-002  -.4947020-002

FIELD STRENGTHS AT HT =  490.0000
```

SAMPLE OUTPUT

```
EX=   -.8310647-001  -.2532007-001    EY=    .2055134-002  -.1073309-001    EZ=    .2712196-002  -.9695892-002
HX=   -.5125973-001   .2846279+000    HY=   -.2142045+001  -.6596929+000    HZ=    .2061171-002  -.1077369-001

FIELD STRENGTHS AT HT =  495.0000
EX=    .6599372-001  -.5758574-001    EY=    .8085582-002   .7482845-002    EZ=    .6848420-002   .7491271-002
HX=   -.2124382+000  -.1923065+000    HY=    .1677609+001  -.1455201+001    HZ=    .8117094-002   .7509664-002

FIELD STRENGTHS AT HT =  500.0000
EX=   -.5456617-001   .6942453-001    EY=   -.9413446-002  -.5894200-002    EZ=   -.8190101-002  -.8134202-002
HX=    .2422898+000   .1480235+000    HY=   -.1364766+001   .1726200+001    HZ=   -.9449693-002  -.5914851-002
```

PROGRAM VERIFICATION

A variety of comparisons were made between the WKB extended height gains and the full-wave Runge-Kutta results. Two representative examples of the comparisons are given in tables 1 and 2.

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GLOBAL NIGHTTIME IONOSPHERE(SAT. NIGHT ABOVE 99, H'=87 BELOW 99)

AZIM=87.8 DEG,CODIP=6.6 DEG,MAGFLD=5.2×10^{-1} GAUSS

FREQ=17.8 KHZ,SIGMA=10.0×10^{-6}S/M,EPSLON=4.4×10^{-11}F/M

HY NORMALIZED TO 1 AT THE GROUND

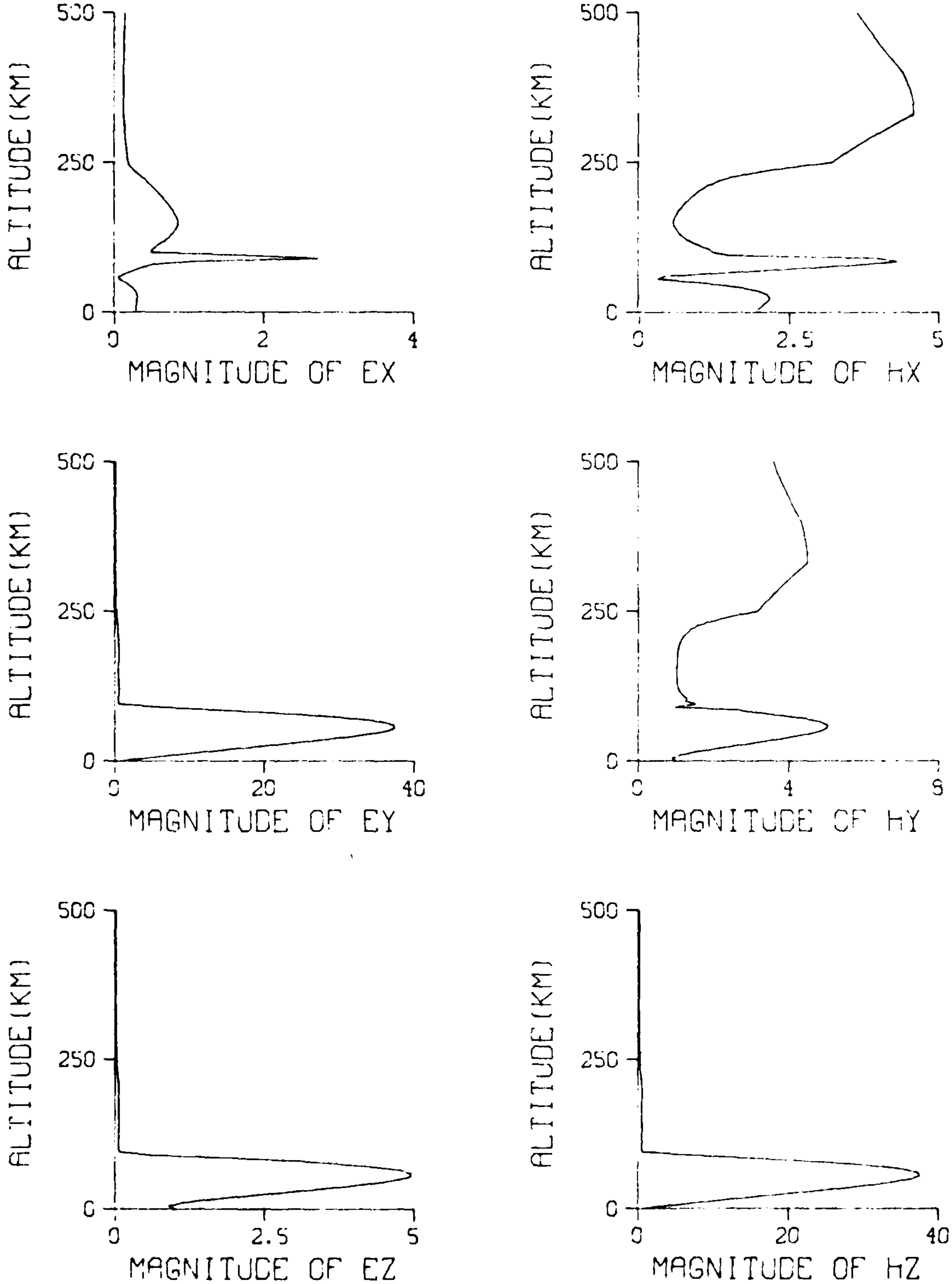

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Table 1 presented results in the VLF band at 17.8 kHz. Table 2 shows results at lower ELF (75 Hz) for the electron and ion density profiles and collision frequency profiles shown below:

SATELLITE NIGHT AMBIENT PROFILE			
800.00	5.00+004	5.00+004	1.00-040
700.00	7.00+004	7.00+004	1.00-040
600.00	1.10+005	1.10+005	1.00-040
500.00	2.00+005	2.00+005	1.00-040
400.00	4.00+005	4.00+005	1.00-040
370.00	4.30+005	4.30+005	1.00-040
350.00	4.40+005	4.40+005	1.00-040
330.00	4.30+005	4.30+005	1.00-040
300.00	3.00+005	3.00+005	1.00-040
250.00	1.00+005	1.00+005	1.00-040
225.00	5.00+003	5.00+003	1.00-040
220.00	3.20+003	3.20+003	1.00-040
210.00	1.68+003	1.68+003	1.00-040
200.00	1.00+003	1.00+003	1.00-040
190.00	6.50+002	6.50+002	1.00-040
180.00	4.60+002	4.60+002	1.00-040
170.00	3.45+002	3.45+002	1.00-040
160.00	2.82+002	2.82+002	1.00-040
155.00	2.60+002	2.60+002	1.00-040
150.00	2.50+002	2.50+002	1.00-040
145.00	2.55+002	2.55+002	1.00-040
140.00	2.80+002	2.80+002	1.00-040
130.00	3.70+002	3.70+002	1.00-040
120.00	5.80+002	5.80+002	1.00-040
112.00	1.10+003	1.10+003	1.00-040
110.00	1.30+003	1.30+003	1.00-040
106.00	1.70+003	1.70+003	1.00-040
104.00	1.90+003	1.90+003	1.00-040
102.00	1.98+003	1.98+003	1.00-040
100.00	2.00+003	2.00+003	1.00-040
99.00	1.95+003	1.95+003	1.00-040
95.00	5.82+002	6.30+002	4.80+001
90.00	3.15+002	4.11+002	9.60+001
85.00	1.97+002	4.11+002	2.14+002
80.00	5.09+001	4.11+002	3.60+002
75.00	3.14+000	4.11+002	4.08+002
70.00	3.27-002	4.11+002	4.11+002
65.00	1.00-002	5.33+002	5.33+002
60.00	5.73-003	7.66+002	7.66+002
55.00	3.39-003	1.09+003	1.09+003
50.00	2.06-003	1.54+003	1.54+003
45.00	1.22-003	2.11+003	2.11+003
40.00	6.74-004	2.73+003	2.73+003
35.00	3.47-004	3.25+003	3.25+003
30.00	1.67-004	3.55+003	3.55+003
25.00	7.70-005	3.69+003	3.69+003
20.00	3.43-005	3.65+003	3.65+003
15.00	1.50-005	3.63+003	3.63+003
10.00	6.58-006	3.72+003	3.72+003
5.00	3.43-006	4.48+003	4.48+003
.00	1.80-006	5.30+003	5.30+003

COLLFREQ			
800.00	5.00+001	7.00-004	7.00-004
700.00	7.00+001	2.00-003	2.00-003
600.00	1.15+002	1.00-002	1.00-002
500.00	2.00+002	5.00-002	5.00-002
400.00	3.80+002	1.80-001	1.80-001
370.00	3.90+002	3.00-001	3.00-001
350.00	3.80+002	3.50-001	3.50-001
330.00	3.50+002	5.00-001	5.00-001
300.00	2.80+002	7.00-001	7.00-001
250.00	1.05+002	4.50-001	4.50-001
225.00	3.50+001	9.00-001	9.00-001
220.00	3.00+001	1.00+000	1.00+000
210.00	3.30+001	1.30+000	1.30+000
200.00	4.50+001	2.00+000	2.00+000
150.00	1.60+003	4.50+001	4.50+001
120.00	1.00+004	3.00+002	3.00+002
100.00	3.90+004	8.00+003	8.00+003
.00	4.30+011	1.07+010	1.07+010

The comparison between the full wave calculated field components and the WKB calculations are for the parameters included as part of the Table legend. Given in the table are all six field components at 400,600 and 800 km. The WKB result is for TOPHT = 250 km and the agreement is good to about 1% in this case which is typical of the lower ELF band.

	Field → Height Km ↓	E_x Re	Im	E_y Re	Im	E_z Re	Im	H_x Re	Im	H_y Re	Re	H_z Re	Im
FULL WAVE TOPHT = 500 Km	250	-.119	.132	-.133	-.118	-.016	-.013	2.362	2.100	-2.104	2.365	-.133	-.119
	350	.119	.020	-.019	.129	-.002	.014	.723	-4.449	4.450	.723	-.019	.120
	500	.102	.100	-.099	.102	-.011	.012	2.496	-2.571	2.573	2.498	-.100	.103
WKB TOPHT = 100 Km	250	-.108	.131	-.136	-.129	-.016	-.014	2.568	2.062	-2.116	2.226	-.136	-.129
	350	.115	.014	-.024	.125	-.002	.015	.511	-4.668	4.292	.836	-.024	.125
	500	.102	.091	-.108	.104	-.012	.013	2.454	-2.813	2.421	2.497	-.108	.105
WKB TOPHT = 110 Km	250	-.119	.134	-.134	-.118	-.016	-.013	2.395	2.110	-2.098	2.389	-.134	-.119
	350	.120	.019	-.019	.120	-.002	.014	.701	-4.496	4.474	.690	-.019	.120
	500	.104	.099	-.099	.103	.011	.013	2.501	-2.614	2.606	2.484	-.100	.104
WKB TOPHT = 120 Km	250	-.117	.135	-.132	-.118	-.016	-.013	2.406	2.118	-2.071	2.382	-.132	-.119
	350	.120	.017	-.020	-.119	.002	-.014	.702	-4.515	4.445	.663	-.020	.119
	500	.105	.098	-.099	.102	.011	.012	2.510	-2.627	2.599	2.453	-.100	.102
WKB TOPHT = 130 Km	250	-.118	.135	-.130	-.119	-.016	-.013	2.395	2.137	-2.088	2.382	-.131	-.119
	250	.121	.018	-.021	.118	-.002	.014	.734	-4.517	4.457	.683	-.021	.119
	500	.104	.099	-.100	.101	-.011	.012	2.531	-2.613	2.598	2.472	-.100	.101
WKB TOPHT = 150 Km	250	-.119	.133	-.134	-.117	-.016	-.013	2.380	2.090	-2.092	2.389	-.134	-.117
	350	.120	.019	-.018	.119	-.002	.014	.688	-4.463	4.469	.682	-.018	.120
	500	.103	.099	-.098	.103	-.011	.013	2.477	-2.598	2.606	2.477	-.098	.104

TABLE 1. HEIGHT GAIN COMPARISONS FOR "GLOBAL NIGHTTIME IONOSPHERE" AT 17.8 KHZ. (See sample input for geomagnetic and ground parameters.)

	Field → Height Km ↓	E_x Re(10^{-2})	E_x Im(10^{-2})	E_v Re(10^{-2})	E_v Im(10^{-2})	E_z Re(10^{-2})	E_z Im(10^{-2})	H_x Re(10^{-2})	H_x Im(10^{-2})	H_y Re(10^{-2})	H_y Im(10^{-2})	H_z Re(10^{-2})	H_z Im(10^{-2})
FULL WAVE	400	.212	.057	-.055	.203	.032	-.117	.286	-1.055	1.105	.300	-.052	.240
TOPHT = 800 Km	600	.095	.289	-.276	.090	.159	-.052	.746	-.245	.256	.782	-.316	.122
	800	.228	.291	-.279	.217	.161	-.125	.510	-.396	.414	.534	-.312	.269
WKB	400	.212	.057	-.055	.203	.032	-.117	.284	-1.048	1.098	.297	-.052	.240
TOPHT = 250 Km	600	.095	.287	-.274	.090	.158	-.052	.744	-.244	.256	.779	-.315	.121
	800	.227	.290	-.277	.216	.160	-.125	.507	-.395	.413	.531	-.311	.268

TABLE 2. HEIGHT GAIN COMPARISONS FOR "SATELLITE NIGHT AMBIENT PROFILE" AT 75 HZ. (Geomagnetic field = .5 x 10^{-4} w/m^2, AZIM = 270°, DIP = 60°, ground conductivity = 3 siemens/m, ground permittivity = .7172 x 10^{-9} farads/m, ground eigenangle: 84.295°, -33.075°).

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APPENDIX:

WKBHTG PROGRAM LISTING

```
C      PROGRAM DRIVER
C    THE DRIVER PROGRAM ALTERNATELY CALLS
C    FOR THE INPUT OF DATA ON THE STANDARD
C    INPUT UNIT AND CALLS FOR THE COMPUTATION
C    OF HEIGHT GAIN FUNCTIONS BY WAVFLD.
C
      IMPLICIT  REAL*8 (A-H,O-Z)
      COMPLEX*16 EX(129), EY(129), EZ(129),
     $          HX(129), HY(129), HZ(129)
     $,THETA
      REAL*8 MAGFLD,LWSTHT
C
      COMMON/WFINPT/THETA,FREQ,AZIM,CODIP,MAGFLD,COEFNU(5),EXPNU(5),
     $TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
      COMMON/EXC IN/IEXC
C
      ISTART = 1
  100 CALL XINPUT (ISTART, ISTOP)
      ISTART = 0
      DO 200 J=1,129
      EX(J) = 0.0
      EY(J) = 0.0
      EZ(J) = 0.0
      HX(J) = 0.0
      HY(J) = 0.0
  200 HZ(J) = 0.0
      CALL WAVFLD(EX,EY,EZ,HX,HY,HZ)
      IF(IEXC .EQ. 0)GO TO 250
      JHT = WKBHT/DELHT+1.01
      HT = 0.
      PRINT 176
      PRINT 174
      DO 300 IHT = 1,JHT
      PRINT 175,HT,EX(IHT),EY(IHT),EZ(IHT),HX(IHT),HY(IHT),HZ(IHT)
  300 HT = HT+DELHT
  250 CONTINUE
      IF(ISTOP .EQ. 0)GO TO 100
  174 FORMAT(//,' HEIGHT GAINS NORMALIZED FOR USE WITH WKB MODE SUMMING
     $FORMULAS',/)
  175 FORMAT(/,' FIELD STRENGTHS AT HT =',F10.4,/,
     $' EX=',E17.7,E15.7,5X,' EY=',E17.7,E15.7,5X,
     $' EZ=',E17.7,E15.7,/,' HX=',E17.7,E15.7,5X,
     $ ' HY=',E17.7,E15.7,5X,' HZ=',E17.7,E15.7)
  176 FORMAT('1')
      END
```

```
      SUBROUTINE XINPUT (ISTART, ISTOP)
C
C   XINPUT READS IN IONOSPERIC INPUT
C   DATA (VIA NAMELIST), AS WELL AS
C   ELECTRON OR ION DENSITY AND
C   COLLISION FREQUENCY PROFILES. THIS
C   ROUTINE SHOULD BE CALLED PRIOR TO
C   CALLING WAVFLD.  ISTART = 1 INDICATES
C   THAT A NEW SET OF INPUT DATA IS TO BE
C   READ, ISTART = 0 INDICATES AN UPDATE
C   OF EXISTING DATA.  ISTOP = 1 INDICATES
C   THE END OF INPUT DATA FOR THIS JOB.
C   ISTOP = 0 INDICATES MORE INPUT DATA
C   APPEARS IN THE DATA DECK.
C
      IMPLICIT REAL *8 (A-H,O-Z)
      DIMENSION ED(5),COLL(5)
      CHARACTER*4 BCD(20)
      CHARACTER*4 LABEL2(20)
      COMMON/WFLABL/LABEL2
      COMMON/WFINPT/THETA,FREQ,AZIM,CODIP,MAGFLD,COEFNU(5),EXPNU(5),
     $TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
     $             LHT,MHT,CHARGE(5),RATIOM(5),NRSPEC
      COMMON/EXC IN/IEXC
      COMMON/ITRAT/ITR
      REAL*8 MAGFLD,LWSTHT
      COMPLEX*16  THETA
C
      NAMELIST/DATUM/THETA,FREQ,IDBG,TOPHT,LWSTHT,WKBHT,DELHT,PRECSN,
     $AZIM,CODIP,MAGFLD,COEFNU,EXPNU,ALPHA,SIGMA,EPSLON,ISO,
     $IEXC,ITR,H
      NAMELIST  /SPECIE/ NRSPEC, CHARGE, RATIOM
C
C
C
      IDAT = 0
      ISTOP = 1
      ICOLL = 1
      IF (ISTART.NE.0)  ICOLL = 0

      PRINT 904
  100 READ 900, BCD
      PRINT 901, BCD
      IF(BCD(1) .EQ. 'DATU') GO TO 200
      IF(BCD(1) .EQ. 'SPEC') GO TO 300
      IF(BCD(1) .EQ. 'COLL') GO TO 400
      IF(BCD(1) .EQ. 'PROF') GO TO 500
      PRINT 904
      IF(BCD(1) .EQ. 'STOP') GO TO 120
      IF(BCD(1) .NE. 'QUIT') GO TO 800
      ISTOP = 0
  120 IF (IDAT.EQ.0.AND.ISTART.NE.0)  GO TO 800
```

```
      IF (ICOLL.NE.0)  RETURN
      COLLHT(1) = TOPHT
      COLLHT(2) = 0.0
      DO 150  J = 1,NRSPEC
      COLLFR(2,J) = DLOG (COEFNU(J))
      COLLFR(1,J) = COLLFR(2,J) + 1000.0 * TOPHT * EXPNU(J)
  150 CONTINUE
      RETURN
C
200   IF(BCD(2) .NE. 'MFOL') GO TO 800
      IDAT = 1
      PREVNU = COEFNU(1)
      COEFNU(1) = 0.0
      READ (5, DATUM)
      IF (COEFNU(1).NE.0.0)  ICOLL = 0
      IF (COEFNU(1).EQ.0.0)  COEFNU(1) = PREVNU
  249 WRITE (6, DATUM)
      GO TO 100
C
  300 READ (5, SPECIE)
      WRITE (6, SPECIE)
      GO TO 100
C
400   IF(BCD(2) .NE. 'FREQ') GO TO 800
      ICOLL = 1
      L = 1
  410 READ 902, HT, COLL
      IF (DABS(HT-999.99).LT.0.01)  GO TO 430
      IF (L.GT.25)  GO TO 800
      IF(L .NE. 1 .AND. HT .GE. COLLHT(L-1)) GO TO 800
      DO 411 M=1,NRSPEC
      IF(COLL(M) .LE. 0.0) COLL(M)=1.0D-40
411   CONTINUE
      PRINT 903,HT,(COLL(M),M=1,NRSPEC)
      COLLHT(L) = HT
      DO 415 M=1,NRSPEC
415   COLLFR(L,M)=DLOG(COLL(M))
      L = L + 1
      GO TO 410
430   PRINT 903,HT
      GO TO 100
C
500   IF(BCD(2) .NE. 'ILE ') GO TO 800
      READ 900, LABEL2
      PRINT 901,LABEL2
      L=1
510   READ 902,HT,ED
      IF(DABS(HT-999.99) .LT. 0.01) GO TO 530
      IF (L.GT.100) GO TO 800
      IF(L .NE. 1 .AND. HT .GE. ENHT(L-1)) GO TO 800
      ENHT(L) = HT
      IF(NRSPEC .EQ. 3) ED(3) = ED(2)-ED(1)
      DO 511 M=1,NRSPEC
      IF(ED(M) .LE. 0.0) ED(M)=1.0D-40
511   CONTINUE
      PRINT 903,HT,(ED(M),M=1,NRSPEC)
      DO 515 M=1,NRSPEC
```

```
515   ENLOG(L,M) = DLOG(ED(M))
      L = L+1
      GO TO 51C
530   PRINT 903,HT
      GO TO 100
C
C     ERROR EXIT
  800 PRINT 910
      STOP
900   FORMAT (20A4)
901   FORMAT (1X,20A4)
902   FORMAT(F7.2,4X,5(1X,E9.2))
903   FORMAT(1X,F7.2,5X,5(1PE9.2,6X))
904   FORMAT('1',//)
910   FORMAT ('1ERROR IN DATA DECK DETECTED',/,
     $ ' IN SUBROUTINE XINPUT')
      END
```

```
      SUBROUTINE WF DENS (HT, EN, COLL)
C
C   WF DENS COMPUTES THE ION DENSITY
C   AND COLLISION FREQUENCY FOR EACH
C   SPECIE BY LOGARITHMIC INTERPOLATION
C   OF THE CORRESPONDING PROFILES.
C   PROFILE VALUES ARE INTERPOLATED BETWEEN
C   ENTRIES MHT AND MHT+1 (LHT AND LHT+1).
C
      IMPLICIT REAL *8 (A-H,O-Z)
      COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
     $              LHT,MHT,CHARGE(5),RATIOM(5),NRSPEC
      DIMENSION  EN(5), COLL(5), DELE(5), DELC(5)
      COMMON/PRIMES/DELE,DELC
      DATA EPSHT/5.D-4/
C
      LUCKY=0
      MUCKY=0
      IF (LHT.EQ.0) LHT=1
      IF (MHT.EQ.0) MHT=1

   10 IF (HT.GE.ENHT(LHT+1)-EPSHT .AND. HT.LT.ENHT(LHT)+EPSHT) GO TO 20
      IF (LUCKY.EQ.1) GO TO 30
      LHT=LHT-1
      IF (LHT.EQ.0) LHT=1
      IF (LHT.EQ.1) LUCKY=1
      GO TO 10
   30 LHT=LHT+1
      IF (LHT.GT.101) GO TO 899
      GO TO 10

   20 IF(HT.GE.COLLHT(MHT+1)-EPSHT.AND.HT.LT.COLLHT(MHT)+EPSHT)GOTO 100
      IF (MUCKY.EQ.1) GO TO 40
      MHT=MHT-1
      IF (MHT.EQ.0) MHT=1
      IF (MHT.EQ.1) MUCKY=1
      GO TO 20
   40 MHT=MHT+1
      IF (MHT.GT. 26) GO TO 899
      GO TO 20
C
  100 IF (LHT.EQ.LSAVE) GO TO 200
      DO 150  K = 1,NRSPEC
      DELE(K) = (ENLOG(LHT+1,K) - ENLOG(LHT,K))
     $ / (ENHT(LHT+1) - ENHT(LHT))
  150 CONTINUE
      LSAVE = LHT
C
  200 IF (MHT.EQ.MSAVE)  GO TO 300
      DO 250  K = 1,NRSPEC
      DELC(K) = (COLLFR(MHT+1,K) - COLLFR(MHT,K))
     $ / (COLLHT(MHT+1) - COLLHT(MHT))
  250 CONTINUE
      MSAVE = MHT
```

```
  300 DH = HT - ENHT(LHT)
      DC = HT - COLLHT(MHT)
      DO 500  K = 1,NRSPEC
      EN(K) = DEXP (ENLOG(LHT,K) + DH * DELE(K))
      COLL(K)  = DEXP (COLLFR(MHT,K) + DC * DELC(K))
  500 CONTINUE
      RETURN
  899 PRINT 900
  900 FORMAT (' ERROR IN PROFILE INTERPOLATION')
      STOP
      END
```

```
      SUBROUTINE WAVFLD(EX,EY,EZ,HX,HY,HZ)
C
C   WAVFLD CALLS FOR THE DOWNWARD
C   INTEGRATION, AND THEN PERFORMS THE
C   BACK SUBSTITUTION OF NORMALIZING
C   VALUES (SAVED AS DATA BY WESTOR).
C   FIELD STRENGTHS ARE COMPUTED AT
C   HEIGHTS FROM TOPHT TO LWSTHT AT
C   DELHT INCREMENTS, AND ARE RETURNED
C   IN THE LISTS EX, EY, EZ, HX, HY, HZ.
C
      IMPLICIT REAL *8 (A-H,O-Z)
      CHARACTER*4 LABEL2(20)
      COMMON/WFLABL/LABEL2
      COMMON/START/INEX, INEY, INHX, INHY
      COMMON/WF FLAG/PRECSN,ISO.IDBG
      COMMON/WF SAVE/P(4,2),M31,M32,M33,ORTHO,ANORM,BNORM,HT,LEVL
      COMMON/CS/C,S,CI,SI
      COMMON  /WFINPT/ THETA, FREQ,
     $AZMUTH,CODIP,MAGFLD,COEFNU(5),EXPNU(5),
     $ TOPHT, LWSTHT, WKBHT,DELHT, H,
     $ALPHA,SIGMA,EPSLON
      COMMON/EXC IN/IEXC
      COMMON/D RX TX/EYD,EZD,RBAR11,RBAR22
      REAL*8  MAGFLD, LWSTHT
      COMPLEX*16  EX(1), EY(1), EZ(1),
     $ HX(1), HY(1), HZ(1),
     $            P,M31,M32,M33,ORTHO,
     $           C,S,CI,SI,
     $           THETA,
     $           EYD,EZD,
     $           INEX,INEY,INHX,INHY,
     $           B(2),W(4),O SUM
     $          ,EXSTOR,EYSTOR,EZSTOR,HXSTOR,HYSTOR,HZSTOR
     $           ,RBAR11,RBAR22
      REAL*4 XARAY(6,129).YARAY(129),XARRAY(129),XMIN,XMAX,XOR,XSTEP,
     $        XAXIS,YOR,YSTEP,YAXIS
      REAL*4 PORX(6)/3*1.5,3*5.0/
      REAL*4 PORY(6)/7.0,4.0,1.0,7.0,4.0,1.0/
      CHARACTER*15 LABEL(6) /'MAGNITUDE OF EX','MAGNITUDE OF EY',
     $                       'MAGNITUDE OF EZ','MAGNITUDE OF HX',
     $                       'MAGNITUDE OF HY','MAGNITUDE OF HZ'/
      EQUIVALENCE(LWSTHT,D)
C
C
      JHT = TOPHT/DELHT+1.01
      TEST = (JHT-1)*DELHT-TOPHT
      IF(DABS(TEST) .GT. 0.0001) GO TO 800
      MHT = LWSTHT/DELHT+1.01
      TEST = (MHT-1)*DELHT-LWSTHT
      IF(DABS(TEST) .GT. 0.0001) GO TO 800
C
C  ITERATION TO SATISFY MODAL EQUATION
      CALL ITRATE
```

```
C
C   COMBINE SOLUTIONS AT GROUND SO THAT
C   THEY SATISFY BOUNDARY CONDITION.
      CALL WF BNDY(B)
C
C   HT GAINS BELOW IONOSPHERE
      WFHT = 0.0
      DO 15 IHT=1,MHT
      CALL HT GAIN(WFHT,EX(IHT),EY(IHT),EZ(IHT),
     $          HX(IHT),HY(IHT),HZ(IHT))
      IF(DABS(WFHT-D) .GT. .001)GO TO 10
      PRINT899
      PRINT 901,WFHT,EX(IHT),EY(IHT),EZ(IHT),HX(IHT),HY(IHT),HZ(IHT)
      EXSTOR = EX(IHT)
      EYSTOR = EY(IHT)
      EZSTOR = EZ(IHT)
      HXSTOR = HX(IHT)
      HYSTOR = HY(IHT)
      HZSTOR = HZ(IHT)
   10 CONTINUE
   15 WFHT = WFHT+DELHT
C
C   PERFORM BACK SUBSTITUTION OF
C   NORMALIZING VALUES.
      O SUM = 0.0
      PRODA = 1.0
      PRODB = 1.0
      IHT = MHT
      CALL WF LOAD
      GO TO 25
C
   21 O SUM = O SUM*ANORM/BNORM+ORTHO
      PRODA = PRODA * ANORM
      IF(PRODA .LT. 1.0D-30) PRODA = 0.0
      PRODB = PRODB * BNORM
      CALL WF LOAD
      DO 23 J=1,4
      P(J,2) = (P(J,2)-O SUM*P(J,1))*PRODB
   23 P(J,1) = P(J, 1) * PRODA
C
C   COMPUTE FIELD STRENGTHS
C   AT PROFILE HEIGHTS.
   25 DO 26 J=1,4
   26 W(J) = P(J,1) * B(1) + P(J,2) * B(2)
      EX(IHT) = W(1)
      EY(IHT) = - W(2)
      EZ(IHT) = -(S    *W(4)+M31*W(1)-M32*W(2))/(1.0+M33)
      HX(IHT) = W(3)
      HY(IHT) = W(4)
      HZ(IHT) = -S*W(2)
      IF(DABS(HT-D) .LT. .001)PRINT901,  HT,EX(IHT)
     $,EY(IHT),EZ(IHT),HX(IHT),HY(IHT),HZ(IHT)
C
      IF(DABS(HT-D) .GT. 0.001) GO TO 41
      EX(IHT) = EXSTOR
      EY(IHT) = EYSTOR
      EZ(IHT) = EZSTOR
```

```
      HX(IHT) = HXSTOR
      HY(IHT) = HYSTOR
      HZ(IHT) = HZSTOR
      EY D = EY(IHT)
      EZ D = EZ(IHT)
   41 CONTINUE
C
      IHT = IHT + 1
      IF (IHT.LE.JHT)  GO TO 21
      INEX=EX(IHT-1)
      INEY=EY(IHT-1)
      INHX=HX(IHT-1)
      INHY=HY(IHT-1)
      IF(LEVL .NE. 0) PRINT 903,LEVL
      CALL WKBVAR(EX,EY,EZ,HX,HY,HZ)
C
C  COMPUTE AND PRINT EXCITATION FACTORS
      IF(IEXC .NE. 0) CALL EXC FAC(S)
      JHT = WKBHT/DELHT+1.01
      HT = 0.
      PRINT898
      PRINT 900
      DO 48 IHT = 1,JHT
      PRINT 901,HT,EX(IHT),EY(IHT),EZ(IHT),HX(IHT),HY(IHT),HZ(IHT)
      XARAY(1,IHT) = CDABS(EX(IHT))
      XARAY(2,IHT) = CDABS(EY(IHT))
      XARAY(3,IHT) = CDABS(EZ(IHT))
      XARAY(4,IHT) = CDABS(HX(IHT))
      XARAY(5,IHT) = CDABS(HY(IHT))
      XARAY(6,IHT) = CDABS(HZ(IHT))
      YARAY(IHT) = HT
   48 HT = HT+DELHT
      CALL BGNPL(1)
      CALL INTAXS
      CALL YAXANG(0.)
      CALL AXSPLT(0.,SNGL(WKBHT),2.0,YOR,YSTEP,YAXIS)
      DO 44 J=1,6
      CALL PHYSOR(PORX(J),PORY(J))
      XMIN = XARAY(J,1)
      XMAX = XARAY(J,1)
      XARRAY(1) = XARAY(J,1)
      DO 42 K=2,JHT
      IF(XARAY(J,K) .LT. XMIN) XMIN=XARAY(J,K)
      IF(XARAY(J,K) .GT. XMAX) XMAX=XARAY(J,K)
      XARRAY(K) = XARAY(J,K)
42    CONTINUE
      CALL AXSPLT(XMIN,XMAX,2.5,XOR,XSTEP,XAXIS)
      CALL TITLE(0,0,LABEL(J),15,'ALTITUDE(KM)',12,XAXIS,YAXIS)
      CALL GRAPH(XOR,XSTEP,YOR,YSTEP)
      CALL CURVE(XARRAY,YARAY,JHT,0)
      CALL ENDGR(J)
44    CONTINUE
      CALL PHYSOR(0.,0.)
      CALL TITLE(0,0,0,0,0,0,1.,1.)
      CALL MESSAG(LABEL2,80,0.8,10.1)
      CALL MESSAG('AZIM=     DEG,CODIP=    DEG,MAGFLD=         GAUSS',
     $  48,1.5,9.8)
```

```
      CALL REALNO(SNGL(AZMUTH),1,2.0,9.8)
      CALL REALNO(SNGL(CODIP),1,3.8,9.8)
      CALL REALNO(SNGL(MAGFLD*1.0E4),-1,5.6,9.8)
      CALL MESSAG('FREQ=       KHZ,SIGMA=          S/M,EPSLON=         F/M',
     $  51,1.5,9.5)
      CALL REALNO(SNGL(FREQ),1,2.0,9.5)
      CALL REALNO(SNGL(SIGMA),-1,3.9,9.5)
      CALL REALNO(SNGL(EPSLON),-1,6.2,9.5)
      CALL MESSAG('HY NORMALIZED TO 1 AT THE GROUND',32,2.5,9.2)
      CALL ENDPL(0)
      IF(IEXC .EQ. 0)GO TO 47
      HT = 0.
      DO 49 IHT = 1,JHT
      EX(IHT) = (1.+RBAR11)*EX(IHT)/EZD
      EY(IHT) = (1.+RBAR22)*EY(IHT)/EYD
      EZ(IHT) = (1.+RBAR11)*EZ(IHT)/EZD
      HX(IHT) = (1.+RBAR22)*HX(IHT)/EYD
      HY(IHT) = (1.+RBAR11)*HY(IHT)/EZD
      HZ(IHT) = (1.+RBAR22)*HZ(IHT)/EYD
   49 HT = HT+DELHT
   47 CONTINUE
      RETURN
C
  800 PRINT 902
      STOP
C
  898 FORMAT('1')
  899 FORMAT(//,' ALTERNATIVE CHECK OF HOW WELL BOUNDARY CONDITIONS ARE
     $SATISFIED',/)
  900 FORMAT(//,' HEIGHT GAINS WITH HY NORMALIZED TO UNITY AT THE GROUND
     $',/)
  901 FORMAT (/,' FIELD STRENGTHS AT HT =',F10.4,/,
     $ ' EX =',E17.7,E15.7,5X,' EY =',E17.7,E15.7,
     $ 5X,' EZ =',E17.7,E15.7,/,' HX =',E17.7,E15.7,
     $ 5X,' HY =',E17.7,E15.7,5X,' HZ =',E17.7,E15.7)
  902 FORMAT (' ERROR IN WAVFLD',/,
     $ ' DELHT DOES NOT DIVIDE TOPHT-LWSTHT EVENLY')
  903 FORMAT(' ','LEVL NOT ZERO. LEVL = ',I3)
      END
```

```
      SUBROUTINE ITRATE
C
C  ITRATE IS THE CONTROL ROUTINE FOR
C  FINDING AN ANGLE, THETA, WHICH
C  SATISFIES THE MODAL EQUATION.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON  /WFINPT/ THETA, FREQ,
     $ AZMUTH, CODIP, MAGFLD, CEFFNU(5), EXPNU(5),
     $ TOPHT, LWSTHT, WKBHT,DELHT, H,
     $ALPHA,SIGMA,EPSLON
      COMMON/ITRAT/ITR
      COMMON/EXC IN/IEXC
      COMMON/DERIV F/DFDT
      COMMON/P MTX/P(16),PI(16)
      COMMON/CS/C,S,CI,SI
      REAL*8 MAGFLD,LWSTHT
      COMPLEX*16 THETA,       DTHETA,I,F,FO,DFDT,DEL T,
     $          C,S,CI,SI
      DATA MXITER/10/
      DATA I/(0.0D0,1.0D0)/
      DATA DTHETA/(5.0D-02,1.0D-02)/
      DATA BND RL/5.0D-02/
      DATA BND IM/5.0D-03/
C
C
      IF(ITR .EQ. 0) GO TO 31
      NR ITER = 0
   11 CALL WF INTG(TOPHT,LWSTHT,DELHT,1)
      CALL FFCT(PI,CI,SI,FO,1)
      CALL FFCT(P,C,S,F,0)
      DFDT = (F-FO)/DTHETA
      DEL T = -F/DFDT
      THETA = THETA+DEL T
      PRINT 900,THETA
      NR ITER = NR ITER+1
      IF(NR ITER .GT. MXITER) STOP
C
      DEL RL = DEL T
      IF(DABS(DEL RL) .GT. BND RL) GO TO 11
      DEL IM = -I*DEL T
      IF(DABS(DEL IM) .GT. BND IM) GO TO 11
C
   31 IF(IEXC .EQ. 0) CALL WF INTG(TOPHT,LWSTHT,DELHT,0)
      IF(IEXC .NE. 0) CALL WF INTG(TOPHT,LWSTHT,DELHT,1)
      IF(IEXC .NE. 0)CALL FFCT(PI,CI,SI,FO,1)
      CALL FFCT(P,C,S,F,0)
      IF(IEXC .NE. 0) DFDT = (F-FO)/DTHETA
      RETURN
C
  900 FORMAT(' ','NEW THETA = ',2F15.8)
      END
```

```
      SUBROUTINE WF INTG(TOPHT,LWSTHT,DELHT,IFLAG)
C
C   WF INTG PERFORMS THE INTEGRATION OF
C   THE P MATRIX DOWN THROUGH THE
C   IONOSPHERE, USING THE TECHNIQUES
C   GIVEN BY PITTEWAY.
C   ACCURACY IS MAINTAINED BY ADJUSTING
C   THE STEPSIZE SO THAT THE P MATRIX
C   IS COMPUTED WITH SUFFICIENT ACCURACY.
C
C  IFLAG=0  INTEG FOR THETA ONLY
C  IFLAG=1  INTEG FOR THETA AND THETA-DTHETA
C
      IMPLICIT REAL *8 (A-H,O-Z)
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMMON/P MTX/P(16),PI(16)
      COMMON/WF SAVE/P SAVE(16),M31 SAV,M32 SAV,M33 SAV,
     $          ORTHO,ANORM,BNORM,HT,LEVL
      COMMON/M MTX/M(3,3)
      COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
     $              LHT,MHT,CHARGE(5),RATIOM(5),NRSPEC
      INTEGER SVFLAG
      REAL*8  LWSTHT
      COMPLEX*16 M31 SAV,M32 SAV,M33 SAV,ORTHO,M
      DIMENSION PREVP(16),TEMPP(16),DPDH(16),PV DPDH(16),DPIDH(16)
      DATA EPSHT/5.0D-04/
      DATA DHMIN/1.0D-03/
C   MINIMUM STEP-SIZE ALLOWED
C
C
      CALL INIT T
      CALL T MTRX(TOP HT)
      CALL WF INIT(P)
      CALL P DERIV(P,DPDH)
      IF(IFLAG .EQ. 0) GO TO 11
      CALL TI MTRX
      CALL WF INIT(PI)
      CALL P DERIV(PI,DPIDH)
   11 CONTINUE
C
      ISTEPS = 0
      KMAX = 0
      LEVL = 0
      HT = TOPHT
      CALL XFER(P,P SAVE,16)
      M31 SAV = M(3,1)
      M32 SAV = M(3,2)
      M33 SAV = M(3,3)
      CALL WF STOR
      WFHT = TOPHT - DELHT
      DELH2 = 0.125D0*DELHT
      SVFLAG=0
C
C   DETERMINE NEXT STEPSIZE TO USE.
```

```
10    IF (SVFLAG.EQ.1) DELH2=SAVDH2
   40 SVFLAG=0
      NODBL = 0
      HTO=HT
      CALL XFER(P,PREVP,16)
      CALL XFER(DPDH,PV DPDH,16)
      HTLIM = WFHT
      IF (ENHT(LHT+1).GT.HTLIM+EPSHT)
     $ HTLIM = ENHT(LHT+1)
      IF (COLLHT(MHT+1).GT.HTLIM+EPSHT)
     $ HTLIM = COLLHT(MHT+1)
      IF (HTO-DELH2.GE.HTLIM+EPSHT)  GO TO 50
      SAVDH2 = DELH2
      SVFLAG = 1
      DELH2 = HTO - HTLIM
C
C   PERFORM NEXT INTEGRATION STEP.
   50 CALL WF STEP(P,DPDH,HT,DELH2,0)
      CALL XFER(P,TEMPP,16)
      M31 SAV = M(3,1)
      M32 SAV = M(3,2)
      M33 SAV = M(3,3)
      HT=HTO
      CALL XFER(PREVP,P,16)
      CALL XFER(PV DPDH,DPDH,16)
      DELH=0.5*DELH2
      CALL WF STEP(P,DPDH,HT,DELH,1)
      CALL P DERIV(P,DPDH)
      CALL WF STEP(P,DPDH,HT,DELH,2)
C   CHECK ACCURACY OF RESULT.
      PMAX = 0.0
      DO 85 J=1,16
      PABS = DABS(P(J)-TEMPP(J))
      IF (P(J).NE.0.) PABS=DABS((P(J)-TEMPP(J))/P(J))
      IF(PMAX .LT. PABS) PMAX = PABS
   85 CONTINUE
C   ADJUST STEPSIZE IF NECESSARY.
      IF (PMAX.LT.PRECSN)  GO TO 100
C
      IF (DELH.GT.DHMIN)  GO TO 95
      IF (KMAX.EQ.0)  PRINT 900, HT
      KMAX = 1
      GO TO 100
   95 CONTINUE
      DELH2 = 0.5 * DELH2
      NODBL = 1
      IF (PMAX.LT.10.0*PRECSN)  GO TO 99
      DELH2 = 0.25 * DELH2
      NODBL = 0
   99 CONTINUE
      HT=HTO
      CALL XFER(PREVP,P,16)
      CALL XFER(PV DPDH,DPDH,16)
      SVFLAG=0
      GO TO 50
C
  100 CALL WF SCAL(P,0)
```

```
      CALL XFER(P,P SAVE,16)
      IF(HT .LT. WFHT+EPSHT) CALL WF STOR
      CALL P DERIV(P,DPDH)
      IF(IFLAG .EQ. 0) GO TO 72
      HT = HTO
      CALL WF STEP(PI,DPIDH,HT,DELH,3)
      CALL P DERIV(PI,DPIDH)
      CALL WF STEP(PI,DPIDH,HT,DELH,4)
      CALL WF SCAL(PI,1)
      CALL P DERIV(PI,DPIDH)
   72 CONTINUE
C
      ISTEPS = ISTEPS+1
      IF(IDBG .EQ. 0) GO TO 73
      IDIV = ISTEPS/50
      IF(ISTEPS .EQ. 50*IDIV) PRINT 902,ISTEPS,HT
   73 CONTINUE
      IF(NO DBL .EQ. 0 .AND. PMAX .LT. 0.5*PRECSN) DELH2 = 2.0*DELH2
C
C    CHECK INTEGRATION AND PROFILE HEIGHTS
      IF (HT.LT.LWSTHT+EPSHT)  GO TO 80
      IF (HT.LT.WFHT+EPSHT)  WFHT = WFHT - DELHT
      IF (HT.LT.ENHT(LHT+1)+EPSHT) LHT=LHT+1
      IF (HT.LT.COLLHT(MHT+1)+EPSHT) MHT=MHT+1
      GO TO 10
C
   80 PRINT 901,ISTEPS
      RETURN
C
  900 FORMAT (' MINIMUM STEPSIZE USED AT HT =',D14.5)
  901 FORMAT (1X,I3,' INTEGRATION STEPS USED IN WAVFLD',/)
  902 FORMAT (1X,I4,' INTEGRATION STEPS, HT =',F9.4)
      END
```

```
      SUBROUTINE WF STEP(P,DPDH,HT,DELH,IFLAG)
C
C  WF STEP INCREMENTS THE SOLUTION OF P
C  FROM HT TO HT-DELH, USING
C  RUNGE-KUTTA INTEGRATION
C
C
C  IFLAG=0  ONE LARGE STEP, THETA
C  IFLAG=1  FIRST SMALL STEP, THETA
C  IFLAG=2  SECOND SMALL STEP, THETA
C  IFLAG=3  FIRST SMALL STEP, THETA-DTHETA
C  IFLAG=4  SECOND SMALL STEP, THETA-DTHETA
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/WF CON/OMEGA,WAVE NR
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMMON/T MTX/T(18)
      COMMON/TM MTX/TM(18)
      DIMENSION P(16),DPDH(16),P0(16),
     $          HDELP0(16),DELP1(16),DELP2(16)
      DIMENSION T SAVE1(18),T SAVE2(18),
     $          TM SAV1(18),TM SAV2(18),TM SAV3(18),TM SAV4(18)
C
C
      HT0 = HT
      DELH K = DELH*WAVE NR
      HDELH K = DELH K*0.5
      DO 11 J=1,16
      P0(J) = P(J)
      HDELP0(J) = -DPDH(J)*HDELH K
   11 P(J) = P0(J)+HDELP0(J)
C
      HT = HT0-0.5*DELH
      IF(IFLAG .LE. 2) CALL T MTRX(HT)
      IF(IFLAG .EQ. 0) CALL XFER(T,T SAVE1,18)
      IF(IFLAG .EQ. 0) CALL XFER(TM,TM SAV2,18)
      IF(IFLAG .EQ. 1) CALL XFER(TM,TM SAV1,18)
      IF(IFLAG .EQ. 2) CALL XFER(TM,TM SAV3,18)
      IF(IFLAG .EQ. 3) CALL XFER(TM SAV1,TM,18)
      IF(IFLAG .EQ. 4) CALL XFER(TM SAV3,TM,18)
      IF(IFLAG .GE. 3) CALL TI MTRX
C
      CALL P DERIV(P,DPDH)
      DO 12 J=1,16
      DELP1(J) = -DPDH(J)*DELH K
   12 P(J) = P0(J)+0.5*DELP1(J)
C
      CALL P DERIV(P,DPDH)
      DO 13 J=1,16
      DELP2(J) = -DPDH(J)*DELH K
   13 P(J) = P0(J)+DELP2(J)
C
      HT = HT0-DELH
      IF(IFLAG .EQ. 0) CALL T MTRX(HT)
```

```
      IF(IFLAG .EQ. 0) CALL XFER(T,T SAVE2,18)
      IF(IFLAG .EQ. 1) CALL XFER(T SAVE1,T,18)
      IF(IFLAG .EQ. 2) CALL XFER(T SAVE2,T,18)
      IF(IFLAG .EQ. 0) CALL XFER(TM,TM SAV4,18)
      IF(IFLAG .EQ. 3) CALL XFER(TM SAV2,TM,18)
      IF(IFLAG .EQ. 4) CALL XFER(TM SAV4,TM,18)
      IF(IFLAG .GE. 3) CALL TI MTRX
C
      CALL P DERIV(P,DPDH)
      THIRD = 1.0D0/3.0D0
      DO 14 J=1,16
      DELP4 = (HDELP0(J)+DELP1(J)+DELP2(J)-DPDH(J)*HDELH K)*THIRD
   14 P(J) = P0(J)+DELP4
      RETURN
C
      END
```

```
      SUBROUTINE WF INIT(P)
C
C  WF INIT COMPUTES THE INITIAL
C  P MATRIX, I.E., THE INITIAL CONDITIONS
C  FOR THE INTEGRATION DP/DZ = -IK*T*P.
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/T MTX/ T11,T31,T41,T12,T32,T42,T14,T34,T44
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMPLEX*16           B3,B2,B1,B0,  I,Q TEMP,DET,SQROOT,
     $           P(4,2),Q(4),
     $           T11,T31,T41,T12,T32,T42,T14,T34,T44
      DATA QMAX/5.0D02/
      DATA I/(0.0D0,1.0D0)/
C
C
      IFAIL = 0
      IF(ISO .NE. 0) GO TO 50
C
      B3 = -(T11+T44)
      B2 = T11*T44-T14*T41-T32
      B1 = -(-T32*(T11+T44)+T12*T31+T34*T42)
      B0 =       -T11*(T32*T44-T34*T42)
     $           +T12*(T31*T44-T34*T41)
     $           -T14*(T31*T42-T32*T41)
C
      CALL QUARTC(B3,B2,B1,B0,Q)
C
      DO 21 J=1,4
      Q ABS = CDABS(Q(J))
      IF(Q ABS .GT. Q MAX) IFAIL = 1
   21 CONTINUE
C
      QI MIN = -I*Q(1)
      J1 = 1
      DO 22 J=2,4
      Q IMAG = -I*Q(J)
      IF(Q IMAG .GT. QI MIN) GO TO 22
      QI MIN = Q IMAG
      J1 = J
   22 CONTINUE
C
      QR MAX = Q(1)
      J2 = 1
      DO 23 J=2,4
      Q REAL = Q(J)
      IF(Q REAL .LT. QR MAX) GO TO 23
      QR MAX = Q REAL
      J2 = J
   23 CONTINUE
C
      IF(J1 .EQ. J2) IFAIL = 1
      IF(IFAIL .NE. 0) GO TO 80
C
```

```
      Q TEMP = Q(J2)
      Q(1) = Q(J1)
      Q(2) = Q TEMP
C
      DO 31 J=1,2
      DET = (T11-Q(J))*(T44-Q(J))-T14*T41
      P(1,J) = (T12*Q(J)-(T12*T44-T14*T42))/DET
      P(2,J) = 1.0
      P(3,J) = Q(J)
   31 P(4,J) = (T42*Q(J)+(T12*T41-T11*T42))/DET
C
   40 IF(IDBG .LT. 2) RETURN
      PRINT 902,Q
      PRINT 901,P
      RETURN
C
   50 B1 = (T11+T44)*0.5
      B0 = T11*T44-T14*T41
      SQROOT = CDSQRT(B1**2-B0)
      Q(1) = B1+SQROOT
      Q(4) = B1-SQROOT
      SQROOT = CDSQRT(T32)
      Q(2) = +SQROOT
      Q(3) = -SQROOT
C
      DO 51 J=1,4
      Q ABS = CDABS(Q(J))
      IF(Q ABS .GT. Q MAX) IFAIL = 1
   51 CONTINUE
      IF(IFAIL .NE. 0) GO TO 80
C
      Q1 TEST = Q(1)+I*Q(1)
      Q4 TEST = Q(4)+I*Q(4)
      IF(Q4 TEST .GT. Q1 TEST) Q(1) = Q(4)
      Q2 TEST = Q(2)+I*Q(2)
      Q3 TEST = Q(3)+I*Q(3)
      IF(Q3 TEST .GT. Q2 TEST) Q(2) = Q(3)
C
      P(1,1) = T14
      P(2,1) = 0.0
      P(3,1) = 0.0
      P(4,1) = -(T11-Q(1))
C
      P(1,2) = 0.0
      P(2,2) = 1.0
      P(3,2) = Q(2)
      P(4,2) = 0.0
      GO TO 40
C
   80 PRINT 900,Q
      STOP
C
  900 FORMAT(' ','ERROR IN WF INIT, Q VALUES TOO LARGE OR DO NOT SORT'
     $          /,' Q = ',4(E15.5,E13.5),//)
  901 FORMAT(' ','P VALUES = ',/,
     $          4(E15.5,E13.5),/,4(E15.5,E13.5))
  902 FORMAT(' ','INITIAL VALUES FROM WF INIT',/,
```

```
      $          ' Q VALUES =',/,2(E15.5,E13.5))
C
       END
```

```
      SUBROUTINE P DERIV(P,DPDH)
C
C  P DERIV COMPUTES THE HEIGHT DERIVATIVES
C  OF THE FIELD VECTORS P ACCORDING TO
C  CLEMMOW AND HEADING (1954).
C  EQUATION IS DP/DZ = -IK*T*P.
C  MULTIPLICATION BY -I IS PERFORMED BY
C  OPERATING ON REAL AND IMAG PARTS.
C  MULTIPLICATION BY K IS PERFORMED
C  IN SUBROUTINE WF STEP.
C
      COMMON/T MTX/ T11,T31,T41,T12,T32,T42,T14,T34,T44
      COMPLEX*16 P(4,2),DERIV,
     $          T11,T31,T41,T12,T32,T42,T14,T34,T44
      REAL*8 DPDH(8,2),PART(2)
      EQUIVALENCE (DERIV,PART)
C
C
      DO 11 J=1,2
      DERIV = T11*P(1,J)+T12*P(2,J)+T14*P(4,J)
      DPDH(1,J) = PART(2)
      DPDH(2,J) = -PART(1)
      DERIV = P(3,J)
      DPDH(3,J) = PART(2)
      DPDH(4,J) = -PART(1)
      DERIV = T31*P(1,J)+T32*P(2,J)+T34*P(4,J)
      DPDH(5,J) = PART(2)
      DPDH(6,J) = -PART(1)
      DERIV = T41*P(1,J)+T42*P(2,J)+T44*P(4,J)
      DPDH(7,J) = PART(2)
   11 DPDH(8,J) = -PART(1)
      RETURN
C
      END
```

```
      SUBROUTINE T MTRX(HT)
C
C  T MTRX   COMPUTES THE MATRICES
C     M- THE SUSCEPTIBILITY TENSOR
C     T- THE COEFFICIENT MATRIX OF
C        THE LINEAR SYSTEM OF O.D.E.
C          DP/DZ = -IK*T*P.
C   NOTE THAT ON           CALL TO
C   ENTRY INIT T,       VARIOUS
C   IONOSPHERIC CONSTANTS ARE COMPUTED.
C
      IMPLICIT REAL *8 (A-H,O-Z)
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMMON/M MTX/M11,M21,M31,M12,M22,M32,M13,M23,M33
      COMMON/T MTX/ T11,T31,T41,T12,T32,T42,T14,T34,T44
      COMMON/TM MTX/TM11,TM31,TM41,TM12,TM32,TM42,TM14,TM34,TM44
      COMMON/CS/C,S,CI,SI
      COMMON  /WFINPT/ THETA, FREQ,
     $ AZMUTH, CODIP, MAGFLD, CEFFNU(5), EXPNU(5),
     $ TOPHT, LWSTHT, WKBHT,DELHT, H,
     $ALPHA,SIGMA,EPSLON
      COMMON/WF CON/OMEGA,WAVE NR
      COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
     $              LHT,MHT,CHARGE(5),RATIOM(5),NRSPEC
      REAL*8  MAGFLD, LWSTHT,
     $        LSQYSQ, MSQYSQ, NSQYSQ,
     $ LMYSQ, LNYSQ, MNYSQ, NU,
     $          LY,MY,NY
      COMPLEX*16 M(3,3),
     $          M11,M21,M31,M12,M22,M32,M13,M23,M33,
     $          T11,T31,T41,T12,T32,T42,T14,T34,T44,
     $          TM11,TM31,TM41,TM12,TM32,TM42,TM14,TM34,TM44,
     $          C,S,CI,SI,CSQ,SSQ,CSQI,SSQI,
     $          THETA,DTHETA,
     $          D,M13D,M23D,
     $          U,USQ,DD,I,IUD,TA,TB
      DIMENSION  Y(5), YSQ(5),  LY(5),  MY(5),
     $  NY(5), LMYSQ(5), LNYSQ(5), MNYSQ(5), EN(5), NU(5),
     $ LSQYSQ(5), MSQYSQ(5), NSQYSQ(5),
     $          COEF EN(5)
      EQUIVALENCE(M11,M)
C
      DATA PI/3.141592653D0/
      DATA DTR/1.745329252D-02/
      DATA COEFFX/3.182357D03/,COEFFY/1.758796D11/
      DATA I/(0.0D0,1.0D0)/
      DATA VELLT/2.997928D05/
      DATA DTHETA/(5.0D-02,1.0D-02)/
C
C
C   CALCULATE THE MATRIX M.
      M(1,1) = 0.0
      M(1,2) = 0.0
      M(1,3) = 0.0
```

```
      M(2,1) = 0.0
      M(2,2) = 0.0
      M(2,3) = 0.0
      M(3,1) = 0.0
      M(3,2) = 0.0
      M(3,3) = 0.0
C
      CALL WF DENS (HT, EN, NU)
      NFLAG = 0
      DO 20 K=1,NRSPEC
C   ADD IN THE CONTRIBUTIONS TO THE
C   SUSCEPTIBILITY TENSOR M FOR EACH
C   SPECIE IN THE IONOSPHERE.
      IF(EN(K) .LT. 1.0E-3) GO TO 20
      NFLAG = 1
      X = COEF EN(K)*EN(K)
      Z = NU(K)*OV OMGA
      U=1.0-I*Z
      USQ=U*U
      DD = -X / (U * (USQ - YSQ(K)) )
      IUD = (Z+I)*DD
      TA = USQ * DD
      M(1,1) = M(1,1) + TA
      M(2,2) = M(2,2) + TA
      M(3,3) = M(3,3) + TA
      M(2,2) = M(2,2) - MSQYSQ(K) * DD
      TA = MY(K)*IUD
      TB = LNYSQ(K) * DD
      M(1,3) = M(1,3) + TA - TB
      M(3,1) = M(3,1) - TA - TB
      IF (ISO.NE.0)  GO TO 20
      M(1,1) = M(1,1) - LSQYSQ(K) * DD
      M(3,3) = M(3,3) - NSQYSQ(K) * DD
      TA = NY(K)*IUD
      TB = LMYSQ(K) * DD
      M(2,1) = M(2,1) + TA - TB
      M(1,2) = M(1,2) - TA - TB
      TA = LY(K)*IUD
      TB = MNYSQ(K) * DD
      M(3,2) = M(3,2) + TA - TB
      M(2,3) = M(2,3) - TA - TB
   20 CONTINUE
C
      CRVTRM=ALPHA*(H-HT)
      M(1,1) = M(1,1) - CRVTRM
      M(2,2) = M(2,2) - CRVTRM
      M(3,3) = M(3,3) - CRVTRM
C
C   CALCULATE THE MATRIX T.
      D = 1.0/(1.0+M33)
      TM41 = 1.0+M11
      TM32 = M22
      TM14 = D
      IF(NFLAG .EQ. 0) GO TO 40
      M13D = M13*D
      M23D = M23*D
      TM41 = TM41-M31*M13D
```

```
      TM11 = M31*D
      TM44 = M13D
      IF(ISO .NE. 0) GO TO 40
      TM32 = TM32-M32*M23D
      TM31 = M31*M23D-M21
      TM12 = M32*D
      TM42 = M32*M13D-M12
      TM34 = M23D
C
   40 T41 = TM41
      T32 = CSQ+TM32
      T14 = 1.0-SSQ*TM14
      IF(NFLAG .EQ. 0) GO TO 70
      T11 = -S*TM11
      T44 = -S*TM44
      IF(ISO .NE. 0) RETURN
      T31 = TM31
      T12 = S*TM12
      T42 = TM42
      T34 = S*TM34
      RETURN
C
C
      ENTRY TI MTRX
      T41 = TM41
      T32 = CSQI+TM32
      T14 = 1.0-SSQI*TM14
      T11 = -SI*TM11
      T44 = -SI*TM44
      IF(ISO .NE. 0) RETURN
      T31 = TM31
      T12 = SI*TM12
      T42 = TM42
      T34 = SI*TM34
      RETURN
C
C
      ENTRY INIT T
C   COMPUTE VARIOUS QUANTITIES
C  WHICH DO NOT VARY WITH HEIGHT.
      LHT = 0
      ISO=0
      IF(MAGFLD .EQ. 0.0) GO TO 250
      IF (DABS(CODIP-90.0).GE.0.15)  GO TO 300
      IF (DABS(AZMUTH-90.0).LT.0.15)  GO TO 250
      IF (DABS(AZMUTH-270.0).GE.0.15)  GO TO 300
  250 ISO = 1
  300 OMEGA = 2000.0 * PI * FREQ
      OV OMGA = 1.0/OMEGA
      WAVENR=OMEGA/VELLT
      SINDIP = DSIN (CODIP*DTR)
      DRCOSL = SINDIP * DCOS (AZMUTH * DTR)
      DRCOSM = SINDIP * DSIN (AZMUTH * DTR)
      DRCOSN = - DCOS (CODIP * DTR)
      DO 60 K=1,NRSPEC
      COEF EN(K) = COEFFX*1.0E6*CHARGE(K)**2/(OMEGA**2*RATIOM(K))
      Y(K) = COEFFY * CHARGE(K) * MAGFLD
```

```
     $ / (OMEGA * RATIOM(K))
      YSQ(K)=Y(K)**2
      LY(K) = DRCOSL*Y(K)
      MY(K) = DRCOSM*Y(K)
      NY(K) = DRCOSN*Y(K)
      LSQYSQ(K)=DRCOSL**2*YSQ(K)
      MSQYSQ(K)=DRCOSM**2*YSQ(K)
      NSQYSQ(K)=DRCOSN**2*YSQ(K)
      LMYSQ(K)=DRCOSL*DRCOSM*YSQ(K)
      LNYSQ(K)=DRCOSL*DRCOSN*YSQ(K)
      MNYSQ(K)=DRCOSM*DRCOSN*YSQ(K)
   60 CONTINUE
      C = CDCOS(THETA*DTR)
      S = CDSIN(THETA*DTR)
      CSQ = C**2
      SSQ = S**2
      CI = CDCOS((THETA-DTHETA)*DTR)
      SI = CDSIN((THETA-DTHETA)*DTR)
      CSQI = CI**2
      SSQI = SI**2
C
   70 T11 = 0.0
      T31 = 0.0
      T12 = 0.0
      T42 = 0.0
      T34 = 0.0
      T44 = 0.0
      RETURN
      END
```

```
      SUBROUTINE WF BNDY(B)
C
C   WF BNDY COMPUTES THE VECTOR B,
C   WHICH DETERMINES HOW TO COMBINE
C   THE SOLUTION VECTORS IN ORDER TO
C   SATISFY THE BOUNDARY CONDITIONS.
C   THIS ROUTINE IS VALID ONLY FOR
C   EIGENANGLES OF THE MODAL EQUATION, AND
C   IS USED TO COMPUTE HEIGHT GAIN FUNCTIONS.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMMON/P MTX/P(4,2),PI(16)
      COMMON/EY GRND/EYG,HYG
      COMMON/DERIV F/DFDT
      COMMON/D RX TX/EYD,EZD,RBAR11,RBAR22
      REAL*4 EOUT
      COMPLEX*16 P,B(2),R(2,2),F,
     $            RBAR11, RBAR22, NURMF, DENMF,
     $ EX1, EX2, EY1, EY2, HX1, HX2, HY1, HY2,
     $         EY,HY,EYG,HYG,
     $          C,S,
     $          DFDT,
     $          EYD,EZD,
     $ FOFR, NUMA, DENA, A, HYSUM, ABPARL, ABPERP,
     $          CTEMP,EXC(3,3),MEXC(3,3)
      DIMENSION PP(16),
     $          LABEL(3),EOUT(6)
      DATA DTR/1.745329252D-02/
      DATA LABEL/'V','E','B'/
C
      IF (IDBG.GT.1)  PRINT 902, P
      EX1=P(1,1)
      EX2=P(1,2)
      EY1=-P(2,1)
      EY2=-P(2,2)
      HX1=P(3,1)
      HX2=P(3,2)
      HY1=P(4,1)
      HY2=P(4,2)
C
      IF (ISO.NE.0)  GO TO 500
C   COMPUTE B, NON-ISOTROPIC CASE.
C   (FROM POLARIZATION EY/HY, SEE BUDDEN).
      NURMF = R(2,1) * (1.0 + RBAR22) * RBAR11
      DENMF = (1.0 + RBAR11) * (1.0 - RBAR22 * R(2,2))
      F OF R=NURMF/DENMF
      NUMA=-(EY1-FOFR*HY1)
      DENA=EY2-FOFR*HY2
      A=NUMA/DENA
      HYSUM=HY1+A*HY2
      B(1) = 1.0 / HYSUM*HY
      B(2) = A / HYSUM*HY
      EYG = (EY1*B(1)+EY2*B(2))/EY
```

```
      GO TO 820
C
C   COMPUTE B. ISOTROPIC CASE.
C   (CHOOSE CORRECTLY POLARIZED SOLUTION).
  500 ABPARL = 1.0 - RBAR11 * R(1,1)
      ABPERP = 1.0 - RBAR22 * R(2,2)
      TEMP A = CDABS (ABPERP)
      TEMP B = CDABS (ABPARL)
      TEMP = TEMP A / TEMP B
      IF (TEMP.LT.1.0D0)  GO TO 600
      B(1) = 1.0/HY1*HY
      B(2) = 0.0
      EYG = 0.0
      GO TO 700
  600 B(1) = 0.0
      B(2) = 1.0/EY2*EY
      HYG = 0.0
  700 IF (TEMP.LT.10.0D0)  GO TO 800
      IF (TEMP.GT.0.1D0)  GO TO 800
      IF (TEMP B.GT.0.1D0)  GO TO 800
      IF (TEMP A.GT.0.1D0)  GO TO 800
  800 PRINT 900, ABPARL, ABPERP
C
  820 CONTINUE
      IF (IDBG.GE.2)  PRINT 905, B
      RETURN
C
C
      ENTRY FFCT(PP,C,S,F,JJ)
      CALL R MTRX(PP,C,R)
      CALL RBARS(C,S,RBAR11,RBAR22,EY,HY)
      IF(IDBG .GE. 1)PRINT 904,R,RBAR11,RBAR22
C
C   COMPUTE MODAL EQN. VALUE
      A = (1.0 - R(1,1) * RBAR11)
      A = A * (1.0 - R(2,2) * RBAR22)
      F = A - R(1,2) * R(2,1) * RBAR11 * RBAR22
      IF(JJ .EQ. 0)PRINT901,F
      RETURN
C
C
      ENTRY EXC FAC(S)
C COMPUTE EXCITATION FACTORS.
      A = S**2*CDSQRT(S)/DFDT*DTR
      CTEMP = A*(1.0+RBAR11)**2*(1.0-RBAR22*R(2,2))/RBAR11
      EXC(1,1) = CTEMP
      EXC(3,1) = -CTEMP
      EXC(1,3) = CTEMP
      EXC(3,3) = -CTEMP
      MEXC(1,2) = CTEMP
      MEXC(3,2) = -CTEMP
      CTEMP = A/S*R(2,1)*(1.0+RBAR11)*(1.0+RBAR22)
      EXC(1,2) = -CTEMP
      EXC(3,2) = CTEMP
      MEXC(1,1) = -CTEMP
      MEXC(3,1) = CTEMP
      MEXC(1,3) = -CTEMP
```

```
      MEXC(3,3) = CTEMP
      CTEMP = A/S*R(1,2)*(1.0+RBAR22)*(1.0+RBAR11)
      EXC(2,1) = -CTEMP
      EXC(2,3) = -CTEMP
      MEXC(2,2) = -CTEMP
      CTEMP = A/S**2*(1.0+RBAR22)**2*(1.0-RBAR11*R(1,1))/RBAR22
      EXC(2,2) = CTEMP
      MEXC(2,1) = CTEMP
      MEXC(2,3) = CTEMP
C
      PRINT 920
      PRINT 922
      CALL MA3(EXC(1,1),EXC(1,2),EXC(1,3),EOUT)
      PRINT 923,(EOUT(K),K=1,6)
      CALL MA3(EXC(2,1),EXC(2,2),EXC(2,3),EOUT)
      PRINT 924,(EOUT(K),K=1,6)
      CALL MA3(EXC(3,1),EXC(3,2),EXC(3,3),EOUT)
      PRINT 925,(EOUT(K),K=1,6)
C
      PRINT 930
      PRINT 932
      CALL MA3(MEXC(1,1),MEXC(1,2),MEXC(1,3),EOUT)
      PRINT 933,(EOUT(K),K=1,6)
      CALL MA3(MEXC(2,1),MEXC(2,2),MEXC(2,3),EOUT)
      PRINT 934,(EOUT(K),K=1,6)
      CALL MA3(MEXC(3,1),MEXC(3,2),MEXC(3,3),EOUT)
      PRINT 935,(EOUT(K),K=1,6)
      RETURN
C
  900 FORMAT (' POLARIZATION VALUES',/,
     $ ' ABPARL =',(D15.5,D13.5),' ABPERP =',(D15.5,D13.5),/)
  901 FORMAT (' MODAL EQN. VALUE =',(D15.5,D13.5))
  902 FORMAT (' P VALUES ON ENTRY TO WF BNDY',/,
     $ 4(E15.5,E13.5),/,4(E15.5,E13.5))
  904 FORMAT (' R = ',2(D15.5,D13.5),/,5X,
     $ 2(D15.5,D13.5),/,' RBAR = ',2(D15.5,D13.5))
  905 FORMAT (' SOLUTION COMBINATION FACTORS',/,
     $ ' B1 =',E15.5,E13.5,'    B2 =',E15.5,E13.5)
  920 FORMAT('1',14X,'ELECTRIC DIPOLE XMTR-ELECTRIC DIPOLE RCVR-EXC(I,J)
     $',//)
  922 FORMAT(' ',24X,'EZ MAG',4X,'EZ ANG',10X,'EY MAG',4X,'EY ANG',10X,
     $'EX MAG',4X,'EX ANG'/)
  923 FORMAT(' ',14X,'V',4X,3(E13.6,2X,F6.3,5X)/)
  924 FORMAT(' ',13X,'HB',4X,3(E13.6,2X,F6.3,5X)/)
  925 FORMAT(' ',13X,'HE',4X,3(E13.6,2X,F6.3,5X)//)
  930 FORMAT(' ',14X,'ELECTRIC DIPOLE XMTR-MAGNETIC DIPOLE RECVR-MEXC(I,
     $J)'//)
  932 FORMAT(' ',24X,'HZ MAG',4X,'HZ ANG',10X,'HY MAG',4X,'HY ANG',10X,
     $'HX MAG',4X,'HX ANG'/)
  933 FORMAT(' ',14X,'V',4X,3(E13.6,2X,F6.3,5X)/)
  934 FORMAT(' ',13X,'HB',4X,3(E13.6,2X,F6.3,5X)/)
  935 FORMAT(' ',13X,'HE',4X,3(E13.6,2X,F6.3,5X)/)
C
      END
```

```
      SUBROUTINE WF SCAL(PP,IFLAG)
C
C   WFSCAL SCALES AND ORTHOGONALIZES THE SOLUTION
C   VECTORS P.  THIS SCALING MUST LATER BE
C   REMOVED TO YIELD CORRECT (UNSCALED) SOLUTIONS.
C
      IMPLICIT  REAL*8 (A-H,O-Z)
      COMMON/WF SAVE/P SAVE(16),M31 SAV,M32 SAV,M33 SAV,
     $          O SUM,APROD,BPROD,HT,LEVL
      COMMON/SAVE/P ETC(27,129)
      COMPLEX*16 P(4,2),
     $                 M31 SAV,M32 SAV,M33 SAV,O SUM,ORTHO
      DIMENSION PR(8,2),PP(16)
      EQUIVALENCE (P,PR)
C
C
      CALL XFER(PP,P,16)
      ANORM = 0.0
      DO 11 J=1,8
   11 ANORM = ANORM+PR(J,1)**2
      ORTHO = 0.0
      DO 12 J=1,4
   12 ORTHO = ORTHO+DCONJG(P(J,1))*P(J,2)
      ORTHO = ORTHO/ANORM
C
      DO 13 J=1,4
   13 P(J,2) = P(J,2)-ORTHO*P(J,1)
      BNORM = 0.0
      DO 14 J=1,8
   14 BNORM = BNORM+PR(J,2)**2
C
      ANORM = 1.0/DSQRT(ANORM)
      BNORM = 1.0/DSQRT(BNORM)
      DO 15 J=1,8
      PR(J,1) = PR(J,1)*ANORM
   15 PR(J,2) = PR(J,2)*BNORM
      CALL XFER(P,PP,16)
      IF(IFLAG .NE. 0) RETURN
C
      O SUM = O SUM+ORTHO*APROD/BPROD
      APROD = APROD*ANORM
      BPROD = BPROD*BNORM
      RETURN
C
C
      ENTRY WF STOR
      LEVL = LEVL+1
      CALL XFER(P SAVE,P ETC(1,LEVL),27)
      O SUM = 0.0
      A PROD = 1.0
      B PROD = 1.0
      RETURN
C
C
```

```
      ENTRY WF LOAD
      CALL XFER(P ETC(1,LEVL),P SAVE,27)
      LEVL = LEVL-1
      RETURN
C
      END
```

```
      SUBROUTINE QUARTC (FOURB3, SIXB2, FOURB1, B0, Q)
C
C   QUARTC FINDS THE ROOTS OF A QUARTIC
C   POLYNOMIAL, FROM THE CLOSED FORM.
C
      IMPLICIT REAL *8 (A-H,O-Z)
      COMPLEX*16
     $          B3,B2,B1,B0,Q,FOURB3,SIXB2,FOURB1,B3SQ,H,I,G,HPRIME,GPRIME
     1,SQROOT,PPLUS,P,LOGP,CBERT0,CBERT1,CBERT2,OMEGA1,OMEGA2,ROOTP,ROOT
     2Q,ROOTR,FNCTON,CPLXI,CLSQRT,CPLXGF,CPLXPF
      REAL*8 MGPLUS,MGMNUS,MAGF
      DIMENSION Q(4), PRI(2), FNCTON(4)
      EQUIVALENCE (P,PRI)
      DATA CPLXI/(0.0D0,1.0D0)/
      DATA OMEGA1/(-5.0D-1, 8.660254038D-1)/
      DATA OMEGA2/(-5.0D-1,-8.660254038D-1)/
      DATA  PRECSN /1.0D-10/
C
C
      B3=FOURB3*0.25
      B2=SIXB2/6.0
      B1=FOURB1*0.25
      B3SQ=B3**2
      H=B2-B3SQ
      I=B0-4.0*B3*B1+3.0*B2**2
      G=B1+B3*(-3.0*B2+2.0*B3SQ)
      HPRIME=-I/12.0
      GPRIME=-G**2/4.0-H*(H**2+3.0*HPRIME)
      SQROOT = CDSQRT (GPRIME**2 + 4.0 * HPRIME**3)
      P=(-GPRIME+SQROOT)*0.5
      MGPLUS=DABS(PRI(1))+DABS(PRI(2))
      PPLUS=P
      P=(-GPRIME-SQROOT)*0.5
      MGMNUS=DABS(PRI(1))+DABS(PRI(2))
      IF (MGPLUS.GT.MGMNUS) P=PPLUS
      LOGP = CDLOG (P)
      CBERT0 = CDEXP (LOGP / 3.0)
      CBERT1=OMEGA1*CBERT0
      CBERT2=OMEGA2*CBERT0
      ROOTP = CDSQRT (CBERT0 - HPRIME / CBERT0 - H)
      ROOTQ = CDSQRT (CBERT1 - HPRIME / CBERT1 - H)
      ROOTR = CDSQRT (CBERT2 - HPRIME / CBERT2 - H)
      IF (CDABS(G) .LE. 1.0D-50) GO TO 5
      SIGN=-ROOTP*ROOTQ*ROOTR*2.0/G
      IF (SIGN.LT.0.0) ROOTR=-ROOTR
    5 Q(1)=+ROOTP+ROOTQ+ROOTR-B3
      Q(2)=+ROOTP-ROOTQ-ROOTR-B3
      Q(3)=-ROOTP+ROOTQ-ROOTR-B3
      Q(4)=-ROOTP-ROOTQ+ROOTR-B3
      DO 20 N=1,4
      ITER = 0
  200 CONTINUE
      ROOTP = Q(N)**4 + FOURB3 * Q(N)**3 + SIXB2 * Q(N)**2
     $ + FOURB1 * Q(N) + B0
```

```
      ROOTQ = 4.0 * Q(N)**3 + 3.0 * FOURB3 * Q(N)**2
     $ + 2.0 * SIXB2 * Q(N) + FOURB1
      ROOTR = ROOTP / ROOTQ
      Q(N) = Q(N) - ROOTR
      IF (CDABS (ROOTR).LT.PRECSN)  GO TO 20
      ITER = ITER + 1
      IF (ITER.LT.10)  GO TO 200
      PRINT 900, ITER, Q(N)
   20 CONTINUE
      RETURN
  900 FORMAT (I3,' ITERATIONS, Q = ',
     $E15.5,E13.5,' FAILS TO CONVERGE')
      END
```

```
      SUBROUTINE R MTRX(P,COSN,R)
C
C  R MTRX   COMPUTES REFLECTION
C   COEFFICIENT MATRIX FROM P MATRIX
C   AND RETURNS IT IN R.
C
      IMPLICIT REAL *8 (A-H,O-Z)
      COMPLEX*16 P(4,2),COSN,R(2,2),
     $            G12, G13, G14, G23, G24, G34,
     $ D00, D11, D22, D12, D21
C
C
      G12=P(1,1)*P(2,2)-P(1,2)*P(2,1)
      G13=P(1,1)*P(3,2)-P(1,2)*P(3,1)
      G14=P(1,1)*P(4,2)-P(1,2)*P(4,1)
      G23=P(2,1)*P(3,2)-P(2,2)*P(3,1)
      G24=P(2,1)*P(4,2)-P(2,2)*P(4,1)
      G34=P(3,1)*P(4,2)-P(3,2)*P(4,1)
C
      D00 = - G13 + COSN * (G34 - G12 + COSN * G24)
      D11 = G13 + COSN * (G34 + G12 + COSN * G24)
      D22 = G13 + COSN * (- G34 - G12 + COSN * G24)
      D12 = 2.0 * COSN * G14
      D21 = 2.0 * COSN * G23
C
      R(1,1) = D11 / D00
      R(2,2) = D22 / D00
      R(1,2) = D12 / D00
      R(2,1) = D21 / D00
      RETURN
      END
```

AD-A107 517 NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA F/G 20/14
A PROGRAM TO COMPUTE ELF/VLF EARTH-IONOSPHERE MODAL HEIGHT GAIN--ETC(U)
SEP 81 R A PAPPERT, L R HITNEY

UNCLASSIFIED NOSC/TR-724 NL

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```
      SUBROUTINE RBARS(C,S,RBAR11,RBAR22,EY,HY)
C
      IMPLICIT REAL *8 (A-H,O-Z)
      COMMON/WFINPT/THETA,FREQ,AZMUTH,CODIP,MAGFLD,CEFFNU(5),EXPNU(5),
     $ TOPHT, LWSTHT, WKBHT,DELHT, H,
     $ALPHA,SIGMA,EPSLON
      COMMON/WF CON/OMEGA,K
      COMMON/EY GRND/EYG,HYG
      COMPLEX *16 THETA,I,NGSQ,C,S,SSQ,SQROOT,RTIORT,IKC,
     $           P0,H10,H20,H1PRM0,H2PRM0,CAPH10,CAPH20,
     $           PD,H1D,H2D,H1PRMD,H2PRMD,CAPH1D,CAPH2D,
     $           PZ,H1Z,H2Z,H1PRMZ,H2PRMZ,
     $           A1ST,A2ND,A3RD,A4TH,A1,A2,A3,A4,
     $           EXD,EXDSQ,EXZ,EXZSQ,
     $           RBAR11,RBAR22,Z1,Z2,
     $           DEN12,DEN34,
     $           EYG,HYG,
     $           EX,EY,EZ,HX,HY,HZ
      REAL *8 K,KVRAOT,KVRATT,NOSQ,NDSQ,NZSQ,MAGFLD,LWSTHT
      EQUIVALENCE(PZ,PD),(H1Z,H1D),(H2Z,H2D),(H1PRMZ,H1PRMD),
     $            (H2PRMZ,H2PRMD),(EXD,EXZ),(EXDSQ,EXZSQ)
      DATA I/(0.0D0,1.0D0)/
      DATA TSTTHM/1.0D01/
      DATA EPSLN0/8.85434D-12/
C
C
      EYG = 1.0
      HYG = 1.0
      ALT = LWSTHT
      D = LWSTHT
      SSQ=S*S
      NGSQ = (EPSLON-I*SIGMA/OMEGA)/EPSLN0
      SQROOT=CDSQRT(NGSQ-SSQ)
      THTIM=I*THETA
      IF(THTIM .GT. TSTTHM) GO TO 10
C
      KVRAOT=DEXP(DLOG(K/ALPHA)/3.0)
      KVRATT=KVRAOT**2
      AVRKOT=1.0/KVRAOT
      AVRKTT=AVRKOT**2*0.5
      NOSQ=1.0-ALPHA*H
      RTIORT=NOSQ/NGSQ*SQROOT
      P0=KVRATT*(NOSQ-SSQ)
      CALL MDHNKL (P0,H10,H20,H1PRM0,H2PRM0)
      CAPH10=H1PRM0+AVRKTT*H10
      CAPH20=H2PRM0+AVRKTT*H20
      A1ST=CAPH20-I*RTIORT*KVRAOT*H20
      A2ND=CAPH10-I*RTIORT*KVRAOT*H10
      A3RD=H2PRM0-I*KVRAOT*SQROOT*H20
      A4TH=H1PRM0-I*KVRAOT*SQROOT*H10
      DEN12 = H20*A2ND-H10*A1ST
      DEN34 = H20*A4TH-H10*A3RD
      IF(D .EQ. 0.0) GO TO 10
C
```

```
      NDSQ=1.0-ALPHA*(H-D)
      PD=KVRATT*(NDSQ-SSQ)
      CALL MDHNKL (PD,H1D,H2D,H1PRMD,H2PRMD)
      CAPH1D=H1PRMD+AVRKTT*H1D
      CAPH2D=H2PRMD+AVRKTT*H2D
C
      A1 = C*NDSQ*(H2D*A2ND-H1D*A1ST)
      A2=I*AVRKOT*(CAPH1D*A1ST-CAPH2D*A2ND)
      A3=I*AVRKOT*(H2PRMD*A4TH-H1PRMD*A3RD)
      A4 = C*(H2D*A4TH-H1D*A3RD)
      RBAR11=(A1-A2)/(A1+A2)
      RBAR22=(A3+A4)/(A4-A3)
      GO TO 40
C
C     FLAT EARTH
   10 IKC = I*K*C
      EXD = CDEXP(-IKC*D)
      EXDSQ = EXD**2
      Z1=(NGSQ*C-SQROOT)/(NGSQ*C+SQROOT)
      Z2=(C-SQROOT)/(C+SQROOT)
      RBAR11=Z1*EXDSQ
      RBAR22=Z2*EXDSQ
      GO TO 40
C
C
      ENTRY HT GAIN(ALTT,EX,EY,EZ,HX,HY,HZ)
      ALT = ALTT
40    IF(THTIM .GT. TSTTHM) GO TO 50
      NZSQ = 1.0-ALPHA*(H-ALT)
      PZ = KVRATT*(NZSQ-SSQ)
      CALL MDHNKL(PZ,H1Z,H2Z,H1PRMZ,H2PRMZ)
      EXPON = DEXP(0.5*ALPHA*ALT)
      HY = (H2Z*A2ND-H1Z*A1ST)*EXPON/DEN12*HYG
      EY = (H2Z*A4TH-H1Z*A3RD)/DEN34*EYG
      EX =       I*AVRKOT*((H2PRMZ*A2ND-H1PRMZ*A1ST)/DEN12*HYG
     $          *EXPON+AVRKTT*HY)/NZSQ
      EZ = -S/NZSQ*HY
      HZ = S*EY
      HX = AVRKOT/I*(H2PRMZ*A4TH-H1PRMZ*A3RD)/DEN34*EYG
      RETURN
C
C     FLAT EARTH
   50 EXZ = CDEXP(-IKC*ALT)
      EXZSQ = EXZ**2
      HY = (1.0+Z1*EXZSQ)/(1.0+Z1)/EXZ*HYG
      EY = (1.0+Z2*EXZSQ)/(1.0+Z2)/EXZ*EYG
      EX = -C*(1.0-Z1*EXZSQ)/(1.0+Z1)/EXZ*HYG
      EZ = -S*HY
      HZ = S*EY
      HX = C*(1.0-Z2*EXZSQ)/(1.0+Z2)/EXZ*EYG
      RETURN
C
      END
```

```
      SUBROUTINE MDHNKL (Z,H1,H2,H1PRME,H2PRME)
      IMPLICIT REAL *8 (A-H,O-Z)
      COMPLEX*16 Z,I,H1,H2,H1PRME,H2PRME,ZPOWER,TERM1,TERM2,
     $          TERM3,ZTERM,TERM,SUM1,SUM2,SUM3,SUM4,SQRTZB,
     $          EXP1,EXP2,EXP3,EXP4,EXP5,GM2F,GPMFP,MPOWER,BETA,RTZ,
     $          CONST1,CONST2,CONST3,CONST4
      DIMENSION A(23), B(23), C(23), D(23), CAP(14)
      DATA A/
     $   9.30436716930000D-01,3.10145572309700D 01,2.06763714873160D 02,
     $   5.74343652425450D 02,8.70217655190080D 02,8.28778719228640D 02,
     $   5.41685437404340D 02,2.57945446383020D 02,9.34584950663100D 01,
     $   2.66263518707400D 01,6.12100043005600D 00,1.15928038448000D 00,
     $   1.84012759441000D-01,2.48330309640000D-02,2.88420801000000D-03,
     $   2.91334142000000D-04,2.58274950000000D-05,2.02568600000000D-06,
     $   1.41557000000000D-07,8.87000000000000D-09,5.01000000000000D-10,
     $   2.60000000000000D-11,1.00000000000000D-12/
      DATA B/
     $   6.78298725140000D-01,1.13049787524000D 01,5.38332321543100D 01,
     $   1.19629404787350D 02,1.53371031778650D 02,1.27809193148880D 02,
     $   7.47422182157200D 01,3.23559386215200D 01,1.07853128738400D 01,
     $   2.85325737403000D 00,6.13603736351000D-01,1.09376780098000D-01,
     $   1.64229399550000D-02,2.10550512200000D-03,2.33167788000000D-04,
     $   2.25282890000000D-05,1.91567100000000D-06,1.44470000000000D-07,
     $   9.72900000000000D-09,5.89000000000000D-10,3.20000000000000D-11,
     $   2.00000000000000D-12,0.00000000000000D 00/
      DATA C/
     $   4.65218358460000D-01,6.20291144619000D 00,2.58454643591500D 01,
     $   5.22130593114000D 01,6.21584039421500D 01,4.87516893663900D 01,
     $   2.70842718702200D 01,1.12150194079600D 01,3.59455750255000D 00,
     $   9.18150064510000D-01,1.91281263439000D-01,3.31222966990000D-02,
     $   4.84244103800000D-03,6.05683682000000D-04,6.55501820000000D-05,
     $   6.19859900000000D-06,5.16550000000000D-07,3.82200000000000D-08,
     $   2.52800000000000D-09,1.50000000000000D-10,8.00000000000000D-12,
     $   0.00000000000000D 00,0.00000000000000D 00/
      DATA D/
     $   6.78298725140000D-01,4.52199150096200D 01,3.76832625080150D 02,
     $   1.19629404787350D 03,1.99382341312250D 03,2.04494709038206D 03,
     $   1.42010214609865D 03,7.11830649673510D 02,2.69632821846030D 02,
     $   7.98912064729000D 01,1.90217158268800D 01,3.71881052333900D 00,
     $   6.07648778323000D-01,8.42202048960000D-02,1.00262148690000D-02,
     $   1.03630127800000D-03,9.38678690000000D-05,7.51243500000000D-06,
     $   5.35074000000000D-07,3.41350000000000D-08,1.96200000000000D-09,
     $   1.02000000000000D-10,5.00000000000000D-12/
      DATA CAP/
     $   1.04166666666667D-01,8.35503472222222D-02,1.28226574556327D-01,
     $   2.91849026464140D-01,8.81627267443758D-01,3.32140828186277D 00,
     $   1.49957629868626D 01,7.89230130115870D 01,4.74451538868000D 02,
     $   3.20749009100000D 03,2.40865496000000D 04,1.98923120000000D 05,
     $   1.79190200000000D 06,1.74843770000000D 07/
C
      DATA I/(0.0D0,1.0D0)/
      DATA ROOT3/1.73205080756888D 00/
      DATA ALPHA/8.53667218838951D-01/
      DATA CONST1/( 2.58819045102522D-01,-9.65925826289067D-01)/
```

```
      DATA CONST2/( 2.588190451025220D-01, 9.659258262890670D-01)/
      DATA CONST3/(-9.659258262890670D-01, 2.588190451025220D-01)/
      DATA CONST4/(-9.659258262890670D-01,-2.588190451025220D-01)/
C
      ZPOWER=1.0
      SUM3=0.0
      SUM4=0.0
      ZMAG=CDABS(Z)
      IF(ZMAG .GT. 4.2) GO TO 70
      IF(ZMAG .GE. 3.2) GO TO 10
      N=12
      GO TO 30
10    IF(ZMAG .GE. 4.1) GO TO 20
      N=15
      GO TO 30
20    N=23
30    SUM1=0.
      SUM2=0.
      ZTERM=-Z**3/200.0
      DO 50 M=1,N
      SUM1=SUM1+A(M)*ZPOWER
      SUM2=SUM2+B(M)*ZPOWER
      SUM3=SUM3+C(M)*ZPOWER
      SUM4=SUM4+D(M)*ZPOWER
      ZPOWER=ZPOWER*ZTERM
      IF(CDABS(ZPOWER) .LE. 1.0D-30) GO TO 60
50    CONTINUE
60    GM2F=I*(Z*SUM2-2.*SUM1)/ROOT3
      GPMFP=I*(SUM4+2.*Z*Z*SUM3)/ROOT3
      H1=Z*SUM2+GM2F
      H2=H1-2.0*GM2F
      H1PRME=SUM4+GPMFP
      H2PRME=H1PRME-2.0*GPMFP
      RETURN
C
70    SUM1=1.0
      SUM2=1.0
      RTZ=CDSQRT(Z)
      SQRTZB=RTZ*Z
      ZTERM=I/SQRTZB
      MPOWER=1.0
      TERM=-1.5/Z
      DO 80 M=1,14
      ZPOWER=ZPOWER*ZTERM
      MPOWER=MPOWER*(-ZTERM)
      TERM1=CAP(M)*ZPOWER
      TERM2=CAP(M)*MPOWER
      SUM1=SUM1+TERM1
      SUM2=SUM2+TERM2
      SUM3=SUM3+M*TERM1
      SUM4=SUM4+M*TERM2
80    CONTINUE
      SUM3=SUM3*TERM
      SUM4=SUM4*TERM
      EXP1=CDEXP(2.*I*SQRTZB/3.)
      EXP2=EXP1*CONST1
      EXP3=CONST2/EXP1
```

```
      EXP4=CONST3*EXP1
      EXP5=CONST4/EXP1
      BETA=ALPHA/CDSQRT(RTZ)
      ZREAL=Z
      ZIMAG=-I*Z
      IF (ZREAL.GE.0.0.OR.ZIMAG.GE.0.0)GO TO 90
      H1=BETA*(EXP2*SUM2+EXP5*SUM1)
      H1PRME=BETA*(EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)+EXP5*(SUM1*(-0.25/Z
     $       -I*RTZ)+SUM3))
      GO TO 110
 90   H1=BETA*EXP2*SUM2
      H1PRME=BETA*EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)
 110  IF (ZREAL.GE.0.0.OR.ZIMAG.LT.0.0)GO TO 120
      H2=BETA*(EXP3*SUM1+EXP4*SUM2)
      H2PRME=BETA*(EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)+EXP4*(SUM2*(-0.25/Z
     $       +I*RTZ)+SUM4))
      RETURN
 120  H2=BETA*EXP3*SUM1
      H2PRME=BETA*EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)
      RETURN
      END
```

```
      SUBROUTINE XFER(A,B,N)
      REAL*8 A,B
      DIMENSION A(1),B(1)
      DO 11 J=1,N
   11 B(J)=A(J)
      RETURN
      END
```

```
      SUBROUTINE MA3(Z1,Z2,Z3,OUT)
      COMPLEX*16 Z1,Z2,Z3
      REAL*8 CDANG
      DIMENSION OUT(6)
      OUT(1)=CDABS(Z1)
      OUT(3)=CDABS(Z2)
      OUT(5)=CDABS(Z3)
      OUT(2)=CDANG(Z1)
      OUT(4)=CDANG(Z2)
      OUT(6)=CDANG(Z3)
      RETURN
      END
```

```
      FUNCTION CDANG(ARG)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMPLEX*16 ARG,ARG PRT
      DIMENSION PARTS(2)
      EQUIVALENCE (ARG PRT,PARTS)

      ARG PRT = ARG
      ARG RL = PARTS(1)
      ARG IM = PARTS(2)
      CDANG = DATAN2(ARG IM,ARG RL)
      RETURN
      END
```

```
      SUBROUTINE WKBVAR(EX,EY,EZ.HX,HY,HZ)
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER SVFLAG
      REAL*8 MAGFLD,LWSTHT
      COMPLEX*16 I,THETA,Q,GAMMA,INTGRQ,INTGAM,SUMQ,SUMGAM,EXPO,QSAV,
     $PARTEX,PARTEY,PARTEZ,PARTHX,PARTHY,PARTHZ,EX(1),EY(1),EZ(1),HX(1),
     $HY(1),HZ(1)
      COMMON  /WFINPT/ THETA, FREQ,
     $ AZMUTH, CODIP, MAGFLD, CEFFNU(5), EXPNU(5),
     $ TOPHT, LWSTHT, WKBHT,DELHT, H,
     $ALPHA,SIGMA,EPSLON
      COMMON/ANSWER/PARTEX,PARTEY,PARTEZ,PARTHX,PARTHY,PARTHZ
      COMMON/WFCON/OMEGA,WAVENR
      COMMON/WFFLAG/PRECSN,ISO,IDBUG
      DATA EPSHT/5.D-4/
      DATA DHMIN/1.D-3/
      DATA I/(0.0D0,1.0D0)/

      IF (WKBHT.LE.TOPHT) RETURN
      JHT = TOPHT/DELHT+1.01
      IHT = JHT+1
      CALL INIT DT
      SUMQ=(0.0D0,0.0D0)
      SUMGAM=(0.0D0,0.0D0)
      HT=TOPHT
      WFHT=TOPHT+DELHT
      DELH2=DELHT/8.

   10 IF (SVFLAG.EQ.1) DELH2=SAVDH2
      SVFLAG=0
      HTLIM=WFHT
      NODBL=0
      IF (HT+DELH2.LE.HTLIM+EPSHT) GO TO 50
      SAVDH2=DELH2
      SVFLAG=1
      DELH2=HTLIM-HT

   50 LFLAG=0
   60 INTGRQ=(0.,0.)
      INTGAM=(0.,0.)
   65 DO 30 M=1,3
      CALL QGAMMA(HT,DELHT,TOPHT,Q,GAMMA)
      IF (M.EQ.2) GO TO110
      INTGRQ=DELH2*Q/6. + INTGRQ
      INTGAM=DELH2*GAMMA/6. + INTGAM
      GO TO 30
  110 INTGRQ=2.*DELH2*Q/3. + INTGRQ
      INTGAM=2.*DELH2*GAMMA/3. + INTGAM
   30 IF (M.NE.3) HT=HT+DELH2/2.

      LFLAG=LFLAG+1
      IF(LFLAG.EQ.3) GO TO 70
      IF (LFLAG.EQ.2) GO TO 65
      QSAV=INTGRQ
```

```
      HT=HT-DELH2
      DELH2=DELH2/2.
      GO TO 60
   70 DELH2=DELH2*2.
      QABS=CDABS(QSAV-INTGRQ)
      IF (CDABS(INTGRQ).NE.0.) QABS=QABS/CDABS(INTGRQ)
      IF (QABS.LT.PRECSN) GO TO 100
      IF (DELH2.GT.DHMIN) GO TO 95
      IF (KMAX.EQ.0) PRINT 900,HT
  900 FORMAT (' MINIMUM STEPSIZE USED FIRST AT HT =',D14.5)
      KMAX=1
      GO TO 100
   95 HT=HT-DELH2
      DELH2=DELH2/2.
      NODBL=1
      IF (QABS.LT.10.*PRECSN) GO TO 99
      DELH2=DELH2/4.
      NODBL=0
   99 SVFLAG=0
      GO TO 50

  100 IF (NODBL.EQ.0 .AND. QABS.LT.PRECSN/3.) DELH2=2.*DELH2
  120 SUMQ=SUMQ+INTGRQ
      SUMGAM=SUMGAM+INTGAM
      IF (HT.LT.WFHT-EPSHT) GO TO 10
      WFHT=WFHT+DELHT
      EXPO=CDEXP(WAVENR*(-SUMQ*I + SUMGAM))
      EX(IHT) = PARTEX*EXPO
      EY(IHT) = PARTEY*EXPO
      EZ(IHT) = PARTEZ*EXPO
      HX(IHT) = PARTHX*EXPO
      HY(IHT) = PARTHY*EXPO
      HZ(IHT) = PARTHZ*EXPO
      IHT = IHT+1
      IF (HT.LT.WKBHT-EPSHT) GO TO 10
      RETURN
      END
```

```
      SUBROUTINE QGAMMA(HT,DELHT,TOPHT,Q,GAMMA)
      IMPLICIT REAL*8(A-H,O-Z)
      COMPLEX*16 C,S,CI,SI,I,QQ(4),Q,GAMMA,AJ,FJ,F,DERIVF,
     $   M(3,3),T(4,4),MPRIME(3,3),TPRIME(4,4),
     $   COEFFB,COEFFC,COEFFD,COEFFE,
     $   A1,A2,A3,A4,A5,A6,B3,B4.B5,B6,
     $   A3PRIM,A4PRIM,A5PRIM,A6PRIM,
     $   B3PRIM,B4PRIM,B5PRIM,B6PRIM,
     $   COEFF0,COEFF1,COEFF2,INEX,INEY,INHX,INHY,
     $   PARTEX,PARTEY,PARTEZ,PARTHX,PARTHY,PARTHZ,
     $   HXNORM,HYNORM,EXNORM,EYNORM
      COMMON/CS/C,S,CI,SI
      COMMON/START/INEX, INEY, INHX, INHY
      COMMON/ANSWER/PARTEX,PARTEY,PARTEZ,PARTHX,PARTHY,PARTHZ
      DATA I/(0.0D0,1.0D0)/

      CALL DDKXMT(HT,M,T,MPRIME,TPRIME)
      COEFFA = 1.0D0
      COEFFB = -(T(1,1)+T(4,4))
      COEFFC = T(1,1)*T(4,4) - T(1,4)*T(4,1) - T(3,2)
      COEFFD = T(3,2)*(T(1,1)+T(4,4)) - T(1,2)*T(3,1) - T(3,4)*T(4,2)
      COEFFE = T(1,1)*(T(3,4)*T(4,2) - T(3,2)*T(4,4))  +
     1         T(1,2)*(T(3,1)*T(4,4) - T(3,4)*T(4,1))  +
     2         T(1,4)*(T(3,2)*T(4,1) - T(3,1)*T(4,2))

      JJ=7
      IF (HT.GT.TOPHT) GO TO 400
   10 CALL QUARTC (COEFFB,COEFFC,COEFFD,COEFFE,QQ)
      QR MAX=QQ(1)
      J2=1
      DO 23 J=2,4
      QREAL=QQ(J)
      IF (QREAL.LT.QR MAX) GO TO 23
      QRMAX=QREAL
      J2=J
   23 CONTINUE
      Q=QQ(J2)

  400 K=1
  500 CONTINUE
      IF (K.GT.21 ) GO TO 510
      F = Q**4*COEFFA + Q**3*COEFFB + Q**2*COEFFC + Q*COEFFD + COEFFE
      DERIVF=4.D0*Q**3*COEFFA + 3.D0*Q**2*COEFFB + 2.D0*Q*COEFFC +COEFFD
      REAL=F/DERIVF
      GINARY=-I*F/DERIVF
      IF  ((REAL**2.LE.1.D-20).AND.(GINARY**2.LE.1.D-30)) GO TO 530
      Q=Q-F/DERIVF
      K=K+1
      GO TO 500
  510 IF (JJ.EQ.7) GO TO 570
      PRINT 520,HT
  520 FORMAT (10X,'DOES NOT CONVERGE AFTER 20  ITERATIONS AT HEIGHT=',
     1  F10:5/)
  530 CONTINUE
```

```
      REAL=Q
      GINARY=-I*Q
      IF (REAL**2 .GT. GINARY**2 .AND. REAL.GT.0.) GO TO 540
      IF (JJ.EQ.13) GO TO 550
  570 JJ=13
      GO TO 10
  550 PRINT 560, HT
  560 FORMAT (10X,'DOES NOT CONVERGE TO THE PROPER Q AT HEIGHT=',F10.5/)
  540 CONTINUE

      A1=-(T(1,1)+T(4,4))
      A2=T(1,1)*T(4,4) - T(1,4)*T(4,1)
      A3=T(1,2)
      A4=T(1,4)*T(4,2) - T(1,2)*T(4,4)
      A5=T(4,2)
      A6=T(4,1)*T(1,2) - T(1,1)*T(4,2)
      B3=T(3,4)
      B4=T(1,4)*T(3,1) - T(3,4)*T(1,1)
      B5=T(3,1)
      B6=T(4,1)*T(3,4) - T(4,4)*T(3,1)
      A3PRIM=TPRIME(1,2)
      A4PRIM=TPRIME(1,4)*T(4,2)+T(1,4)*TPRIME(4,2) -
     1        TPRIME(1,2)*T(4,4)-T(1,2)*TPRIME(4,4)
      A5PRIM=TPRIME(4,2)
      A6PRIM=TPRIME(4,1)*T(1,2)+T(4,1)*TPRIME(1,2) -
     1        TPRIME(1,1)*T(4,2)-T(1,1)*TPRIME(4,2)
      B3PRIM=TPRIME(3,4)
      B4PRIM=TPRIME(1,4)*T(3,1)+T(1,4)*TPRIME(3,1) -
     1        TPRIME(3,4)*T(1,1)-T(3,4)*TPRIME(1,1)
      B5PRIM=TPRIME(3,1)
      B6PRIM=TPRIME(4,1)*T(3,4)+T(4,1)*TPRIME(3,4) -
     1        TPRIME(4,4)*T(3,1)-T(4,4)*TPRIME(3,1)
      AJ=Q*Q+A1*Q+A2
      FJ=2.0D0*Q*AJ + (Q*Q-T(3,2))*(2.0D0*Q+A1) - (A3*B5+B3*A5)
      COEFF0=A4*B6PRIM-A4PRIM*B6+A6*B4PRIM-A6PRIM*B4
      COEFF1=A3*B6PRIM-A3PRIM*B6+A4*B5PRIM-A4PRIM*B5+A5*B4PRIM-
     1        A5PRIM*B4+A6*B3PRIM-A6PRIM*B3
      COEFF2=A3*B5PRIM-A3PRIM*B5+A5*B3PRIM-A5PRIM*B3
      GAMMA=(Q*Q*COEFF2 + Q*COEFF1 + COEFF0)/(2.D0*AJ*FJ)

      NICE=(HT-TOPHT)/DELHT
      IF ( (HT-TOPHT)/DELHT - NICE .NE. 0.0) RETURN
      IF (HT.NE.TOPHT) GO TO 605
      HXNORM=INHX*CDSQRT(AJ*FJ)/(Q*AJ)
      HYNORM=INHY*CDSQRT(AJ*FJ)/(Q*A5+A6)
      EXNORM=INEX*CDSQRT(AJ*FJ)/(Q*A3+A4)
      EYNORM=INEY*CDSQRT(AJ*FJ)/(-AJ)
  605 PARTHX=HXNORM/CDSQRT(AJ*FJ)*(Q*AJ)
      PARTHY=HYNORM/CDSQRT(AJ*FJ)*(Q*A5+A6)
      PARTEX=EXNORM/CDSQRT(AJ*FJ)*(Q*A3+A4)
      PARTEY=EYNORM/CDSQRT(AJ*FJ)*(-AJ)
      PARTHZ=PARTEY*S
      PARTEZ=-(S*PARTHY + M(3,1)*PARTEX + M(3,2)*PARTEY)/(1.+M(3,3))
      RETURN
      END
```

```
      SUBROUTINE DDKXMT(HT,M,T,MPRIME,TPRIME)
      IMPLICIT REAL *8 (A-H,O-Z)
      COMMON/PRIMES/DELE,DELC
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMMON  /WFINPT/ THETA, FREQ,
     $ AZMUTH, CODIP, MAGFLD, CEFFNU(5), EXPNU(5),
     $ TOPHT, LWSTHT, WKBHT,DELHT, H,
     $ALPHA,SIGMA,EPSLON
      COMMON/WF CON/OMEGA,WAVE NR
      COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
     $              LHT,MHT,CHARGE(5),RATIOM(5),NRSPEC
      COMMON/CS/C,S,CI,SI
      REAL*8  MAGFLD, LWSTHT,
     $        LSQYSQ, MSQYSQ, NSQYSQ,
     $ LMYSQ, LNYSQ, MNYSQ, NU,NUPRIM,
     $          LY,MY,NY
      COMPLEX*16 M(3,3),
     $    T(4,4),
     $    MPRIME(3,3),TPRIME(4,4),XPRIME,UPRIME,DDPRIM,IUDPRI,M331,
     $    TAPRIM,TBPRIM,
     $          C,S,CI,SI,CSQ,SSQ,CSQI,SSQI,
     $          THETA,DTHETA,
     $          U,USQ,DD,I,IUD,TA,TB
      DIMENSION DELE(5),DELC(5),ENPRIM(5),NUPRIM(5)
      DIMENSION  Y(5), YSQ(5),  LY(5),  MY(5),
     $  NY(5), LMYSQ(5), LNYSQ(5), MNYSQ(5), EN(5), NU(5),
     $ LSQYSQ(5), MSQYSQ(5), NSQYSQ(5),
     $          COEF EN(5)
C
      DATA PI/3.141592653D0/
      DATA DTR/1.745329252D-02/
      DATA COEFFX/3.182357D03/,COEFFY/1.758796D11/
      DATA I/(0.0D0,1.0D0)/
      DATA VELLT/2.997928D05/
      DATA DTHETA/(5.0D-02,1.0D-02)/
C
C   CALCULATE THE MATRIX M.
      M(1,1) = 0.0
      M(1,2) = 0.0
      M(1,3) = 0.0
      M(2,1) = 0.0
      M(2,2) = 0.0
      M(2,3) = 0.0
      M(3,1) = 0.0
      M(3,2) = 0.0
      M(3,3) = 0.0
      MPRIME(1,1)=0.0
      MPRIME(1,2)=0.0
      MPRIME(1,3)=0.0
      MPRIME(2,1)=0.0
      MPRIME(2,2)=0.0
      MPRIME(2,3)=0.0
      MPRIME(3,1)=0.0
      MPRIME(3,2)=0.0
```

```
      MPRIME(3,3)=0.0
C
      CALL WF DENS (HT, EN, NU)
      DO 10 K=1,NRSPEC
      ENPRIM(K)=EN(K)*DELE(K)
      NUPRIM(K)=NU(K)*DELC(K)
   10 CONTINUE
C
      NFLAG = 0
      DO 20 K=1,NRSPEC
C   ADD IN THE CONTRIBUTIONS TO THE
C   SUSCEPTIBILITY TENSOR M FOR EACH
C   SPECIE IN THE IONOSPHERE.
      IF(EN(K) .LT. 1.0E-3) GO TO 20
      NFLAG = 1
      X = COEF EN(K)*EN(K)
      XPRIME=COEFEN(K)*ENPRIM(K)/WAVENR
      IF(NGLECT .NE. 0) X = -X
      Z = NU(K)*OV OMGA
      IF(NGLECT .NE. 0) Z = -Z
      U=1.0-I*Z
      UPRIME=-I*NUPRIM(K)*OV OMGA/WAVENR
      USQ=U*U
      DD = -X / (U * (USQ - YSQ(K)) )
      DDPRIM=(X*(3.DO*USQ*UPRIME-YSQ(K)*UPRIME) -
     1       XPRIME*(U*(USQ-YSQ(K))) )/(U*(USQ-YSQ(K)))**2
      IUD = (Z+I)*DD
      IUDPRI=NUPRIM(K)*OV OMGA/WAVENR*DD     + (Z+I)*DDPRIM

      TA = USQ * DD
      M(1,1) = M(1,1) + TA
      M(2,2) = M(2,2) + TA
      M(3,3) = M(3,3) + TA
      M(2,2) = M(2,2) - MSQYSQ(K) * DD
      TAPRIM=2.DO*U*UPRIME*DD + USQ*DDPRIM
      MPRIME(1,1)=MPRIME(1,1) + TAPRIM
      MPRIME(2,2)=MPRIME(2,2) + TAPRIM
      MPRIME(3,3)=MPRIME(3,3) + TAPRIM
      MPRIME(2,2)=MPRIME(2,2) - MSQYSQ(K) * DDPRIM

      TA = MY(K)*IUD
      TB = LNYSQ(K) * DD
      M(1,3) = M(1,3) + TA - TB
      M(3,1) = M(3,1) - TA - TB
      TAPRIM=MY(K)*IUDPRI
      TBPRIM=LNYSQ(K)*DDPRIM
      MPRIME(1,3)=MPRIME(1,3) + TAPRIM - TBPRIM
      MPRIME(3,1)=MPRIME(3,1) - TAPRIM - TBPRIM

      IF (ISO.NE.0)  GO TO 20
      M(1,1) = M(1,1) - LSQYSQ(K) * DD
      M(3,3) = M(3,3) - NSQYSQ(K) * DD
      MPRIME(1,1)=MPRIME(1,1) - LSQYSQ(K)*DDPRIM
      MPRIME(3,3)=MPRIME(3,3) - NSQYSQ(K)*DDPRIM
      TA = NY(K)*IUD
      TB = LMYSQ(K) * DD
      M(2,1) = M(2,1) + TA - TB
```

```
      M(1,2) = M(1,2) - TA - TB
      TAPRIM=NY(K)*IUDPRI
      TBPRIM=LMYSQ(K)*DDPRIM
      MPRIME(2,1)=MPRIME(2,1) + TAPRIM - TBPRIM
      MPRIME(1,2)=MPRIME(1,2) - TAPRIM - TBPRIM
      TA = LY(K)*IUD
      TB = MNYSQ(K) * DD
      M(3,2) = M(3,2) + TA - TB
      M(2,3) = M(2,3) - TA - TB
      TAPRIM=LY(K)*IUDPRI
      TBPRIM=MNYSQ(K)*DDPRIM
      MPRIME(3,2)=MPRIME(3,2) + TAPRIM -TBPRIM
      MPRIME(2,3)=MPRIME(2,3) - TAPRIM -TBPRIM
   20 CONTINUE
C
      CRVTRM=ALPHA*(H-HT)
      M(1,1) = M(1,1) - CRVTRM
      M(2,2) = M(2,2) - CRVTRM
      M(3,3) = M(3,3) - CRVTRM
      CURVPR=ALPHA/WAVENR
      MPRIME(1,1)=MPRIME(1,1) + CURVPR
      MPRIME(2,2)=MPRIME(2,2) + CURVPR
      MPRIME(3,3)=MPRIME(3,3) + CURVPR
C
C   CALCULATE THE MATRIX T.

      T(1,1)=-S*M(3,1)/(1.0D0+M(3,3))
      T(4,4)=-S*M(1,3)/(1.0D0+M(3,3))
      T(1,2)= S*M(3,2)/(1.0D0+M(3,3))
      T(3,4)= S*M(2,3)/(1.0D0+M(3,3))
      T(1,3)=0.0D0
      T(2,4)=0.0D0
      T(1,4)=(C*C+M(3,3))/(1.0D0+M(3,3))
      T(2,1)=0.0D0
      T(4,3)=0.0D0
      T(2,2)=0.0D0
      T(3,3)=0.0D0
      T(2,3)=1.0D0
      T(3,1)=M(2,3)*M(3,1)/(1.0D0+M(3,3)) - M(2,1)
      T(4,2)=M(3,2)*M(1,3)/(1.0D0+M(3,3)) - M(1,2)
      T(3,2)= C*C + M(2,2) - M(2,3)*M(3,2)/(1.0D0+M(3,3))
      T(4,1)=1.D0 + M(1,1) - M(1,3)*M(3,1)/(1.0D0+M(3,3))

      M331=1.0D0+M(3,3)
      TPRIME(1,1)=(-S*MPRIME(3,1)*M331+S*M(3,1)*MPRIME(3,3))/M331**2
      TPRIME(4,4)=(-S*MPRIME(1,3)*M331+S*M(1,3)*MPRIME(3,3))/M331**2
      TPRIME(1,2)=( S*MPRIME(3,2)*M331-S*M(3,2)*MPRIME(3,3))/M331**2
      TPRIME(3,4)=( S*MPRIME(2,3)*M331-S*M(2,3)*MPRIME(3,3))/M331**2
      TPRIME(1,3)=0.0D0
      TPRIME(2,4)=0.0D0
      TPRIME(1,4)=( MPRIME(3,3)*M331 - MPRIME(3,3)*(C*C+M(3,3)))/M331**2
      TPRIME(2,1)=0.0D0
      TPRIME(4,3)=0.0D0
      TPRIME(2,2)=0.0D0
      TPRIME(3,3)=0.0D0
      TPRIME(2,3)=0.0D0
      TPRIME(3,1)=( M(2,3)*MPRIME(3,1)*M331+MPRIME(2,3)*M(3,1)*M331 -
```

```
     1            MPRIME(3,3)*M(2,3)*M(3,1) )/M331**2 - MPRIME(2,1)
      TPRIME(4,2)=( M(3,2)*MPRIME(1,3)*M331+MPRIME(3,2)*M(1,3)*M331 -
     1            MPRIME(3,3)*M(3,2)*M(1,3) )/M331**2 - MPRIME(1,2)
      TPRIME(3,2)=MPRIME(2,2) - (MPRIME(2,3)*M(3,2)*M331+
     1           M(2,3)*MPRIME(3,2)*M331-MPRIME(3,3)*M(2,3)*M(3,2) )/
     2           M331**2
      TPRIME(4,1)=MPRIME(1,1) - (MPRIME(1,3)*M(3,1)*M331+
     1           M(1,3)*MPRIME(3,1)*M331-MPRIME(3,3)*M(1,3)*M(3,1) )/
     2           M331**2
      RETURN

      ENTRY INIT DT
      ISO=0
      IF(MAGFLD .EQ. 0.0) GO TO 250
      IF (DABS(CODIP-90.0).GE.0.15)  GO TO 300
      IF (DABS(AZMUTH-90.0).LT.0.15)  GO TO 250
      IF (DABS(AZMUTH-270.0).GE.0.15)  GO TO 300
  250 ISO = 1
  300 OMEGA = 2000.0 * PI * FREQ
      OV OMGA = 1.0/OMEGA
      WAVENR=OMEGA/VELLT
      SINDIP = DSIN (CODIP*DTR)
      DRCOSL = SINDIP * DCOS (AZMUTH * DTR)
      DRCOSM = SINDIP * DSIN (AZMUTH * DTR)
      DRCOSN = - DCOS (CODIP * DTR)
      DO 60 K=1,NRSPEC
      COEF EN(K) = COEFFX*1.0E6*CHARGE(K)**2/(OMEGA**2*RATIOM(K))
      Y(K) = COEFFY * CHARGE(K) * MAGFLD
     $ / (OMEGA * RATIOM(K))
      YSQ(K)=Y(K)**2
      LY(K) = DRCOSL*Y(K)
      MY(K) = DRCOSM*Y(K)
      NY(K) = DRCOSN*Y(K)
      LSQYSQ(K)=DRCOSL**2*YSQ(K)
      MSQYSQ(K)=DRCOSM**2*YSQ(K)
      NSQYSQ(K)=DRCOSN**2*YSQ(K)
      LMYSQ(K)=DRCOSL*DRCOSM*YSQ(K)
      LNYSQ(K)=DRCOSL*DRCOSN*YSQ(K)
      MNYSQ(K)=DRCOSM*DRCOSN*YSQ(K)
   60 CONTINUE
      C = CDCOS(THETA*DTR)
      S = CDSIN(THETA*DTR)
      CSQ = C**2
      SSQ = S**2
      CI = CDCOS((THETA-DTHETA)*DTR)
      SI = CDSIN((THETA-DTHETA)*DTR)
      CSQI = CI**2
      SSQI = SI**2
C
      RETURN
      END
```

```
      BLOCK DATA
C
C   INITIALIZE THE COMMON BLOCK VALUES.
C
      IMPLICIT REAL *8 (A-H,O-Z)
      COMMON  /WFINPT/ THETA, FREQ,
     $ AZMUTH, CODIP, MAGFLD, CEFFNU(5), EXPNU(5),
     $ TOPHT, LWSTHT, WKBHT,DELHT, H,
     $ALPHA,SIGMA,EPSLON
      COMMON/WF FLAG/PRECSN,ISO,IDBG
      COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
     $              LHT,MHT,CHARGE(5),RATIOM(5),NRSPEC
      COMMON/EXC IN/IEXC
      COMMON/ITRAT/ITR
      REAL*8  MAGFLD, LWSTHT
      COMPLEX*16  THETA
C
C
      DATA CEFFNU/1.816D11,4*0.0D0/
      DATA EXPNU/-1.5D-4,4*0.0D0/
      DATA ALPHA/3.14D-4/
      DATA  SIGMA /4.64D0/
      DATA  EPSLON /7.172015D-10/
      DATA  PRECSN /3.0D-5/
      DATA CHARGE/-1.0D0,1.0D0,-1.0D0,1.0D0,-1.0D0/
      DATA  RATIOM /1.0D0,4*5.8D04/
      DATA  NRSPEC /1/
      END
```

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